Deliverable 5-1

Analysis of the barriers to using biomethane in the transport sector

Version 1.1

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March 2025

EXECUTIVE SUMMARY

Transportation plays a crucial role in global economies, facilitating the movement of goods, people, and services across different regions. The global transport system can be divided into several key modes, each with unique characteristics, infrastructure requirements, and economic significance. Major modes of transportation include road, rail, air, marine, and pipeline transports.

Fossil fuels dominate the world transport industry, accounting for over 90% of the sector's energy consumption. The share of biofuels in the global energy consumption in transport is only 6%, bioenergy being mostly used by trucks in road transport.

As the world is moving towards sustainability, the transport sector must reduce its carbon footprint by shifting to low-carbon and renewable fuels and energy carriers. Current trends in transportation related to this transition include the use of biofuels and biomethane, electric vehicles (EVs), green aviation technologies (e.g., sustainable aviation fuels, hydrogen and electric aircraft), sustainable shipping innovations such as liquefied natural gas (LNG), green methanol etc.

Main future energy trends in the world transport includes among other possibilities deployment of biomethane, in both compressed and liquified forms (bio-CNG and bio-LNG). Biomethane provides a sustainable and cost-competitive substitute for fossil fuels, representing one of the few readily available fossil fuel alternatives for long distance and energy intensive transport segments. This makes biomethane a key player in the transition towards a climate neutral economy

Europe is the world's leading producer of biogas and biomethane, European production of biomethane as transport fuel (both bio-CNG and bio-LNG) also continues to grow. The deployment of biomethane to replace fossil fuels requires minimal additional investment of resources and time to develop new infrastructure and technology.

The transition toward low-carbon transport fuels is a key priority within the European Union as part of its broader strategy to achieve climate neutrality by 2050. In this context, natural gas and biomethane have been identified as viable alternatives to conventional fossil fuels, particularly in the transport sector. Several EU Directives provide the regulatory framework for the adoption and promotion of these fuels, which are further supported by national policies. Through a combination of binding targets, financial incentives, and infrastructure development mandates, the EU seeks to accelerate the transition from conventional fossil fuels to cleaner and more sustainable fuel options.

For use as a fuel, biomethane is compressed to at least 200 bar and are filled in *cylinders (tanks)* installed on the vehicles. Compressed biomethane can be used as a car fuel in the same way as compressed natural gas, and therefore is a full-fledged substitute of natural gas. Both diesel and gasoline cars can be *equipped* with bio-CNG units. Many car manufacturers today already have specialized CNG vehicles in their model ranges.

The liquefaction of biomethane is appropriate when it is necessary to transport it over longer distances in the absence of the possibility of supplying it to the natural gas system (GTS or GDS), as well as to increase the transport distance at one gas refuelling.

In Ukraine, petrol (gasoline) and diesel fuel are key energy carriers for road transport, agricultural and construction machinery, and industrial equipment. Diesel fuel is used mainly in freight transport, the agricultural sector and special equipment, while gasoline remains the main type of fuel for passenger cars. In recent years, there has been a tendency to increase the share of diesel fuel in the overall consumption balance due to its economy and higher torque of internal combustion engines.

In Ukraine, there have been traditions and experience of using compressed natural gas (CNG) as a motor fuel for buses and heavy vehicles. There is a network of CNG filling stations located mainly in large cities and along transport highways. Unfortunately, the volume of methane sales at CNG filling stations had trends towards decrease due to the small and permanently decreasing number of vehicles that used this gas as fuel.

Biomethane is one of the most cost-effective ways to decarbonize the energy and transport sectors of the economy. Using biomethane as a motor fuel allows agricultural producers to obtain their own source of energy from waste and residues of their own production. The use of biomethane in public transport can significantly reduce air pollution in large cities. It is advisable to use biomethane not only in road transport, but also in water and rail transport, and not only in compressed but also in liquefied form.

However, it should be noted that today choosing between biomethane and natural gas, the owner of a vehicle in Ukraine is more likely will prefer the latter, since its price is notably lower than the economically justified selling price of compressed biomethane and there are no additional incentives for biomethane refuelling.

It means that biomethane as a transport fuel faces the problem as soon as at the exit of the biomethane plant it will most likely have a higher cost than natural gas. In addition, the infrastructure and processes for the production and retail of bio-CNG and bio-LNG themselves require additional capital and operating costs. As a result, compressed natural gas will have a price advantage over bio-CNG,

Therefore, to implement an economically viable transition to biomethane, financial incentives need to be introduced that monetize GHG emission reductions and sustainability in the use of biomethane.

Another key barrier to the development of biomethane in the transport sector in Ukraine is the absence of approved long-term strategic goals for the bioenergy and biomethane sector. Ukraine lacks a legally binding strategy and roadmap for biomethane production, consumption, and integration into the energy systems. This uncertainty discourages investment, as businesses and financial institutions require clear policy commitments to justify long-term investments in biomethane production facilities and refuelling infrastructure. Additionally, Ukraine lacks national targets and commitments for biomethane use in transport.

A significant barrier to the development of biomethane in Ukraine's transport sector is the absence of a fundamental law specifically regulating its production and use in transport. Another barrier to the adoption of biomethane in Ukraine's transport sector is the absence of established technical requirements for its use as a motor fuel.

One more barrier to the development of biomethane in Ukraine's transport sector is the declining consumption of natural gas as a motor fuel. The number of CNG refuelling stations has been steadily decreasing, reducing accessibility for vehicles that could potentially switch to biomethane.

To overcome the regulatory and policy barriers hindering the growth of biomethane usage in the transport sector, it is crucial to adopt a long-term, strategic approach. One of the most effective ways to address this issue is by:

- Establishment of a domestic GHG emissions trading system that covers transport sector;
- Developing a Bioenergy/Biomethane Strategy and Roadmap till 2050;
- Development of basic law on biomethane use as motor fuel;
- State co-financing of the creation of filling station infrastructure to operate on bio-CNG and bio-LNG;
- Setting of biomethane consumption targets and targets for the number of the gas refuelling stations;
- Establishment of technical standards for biomethane in CNG and LNG applications;
- Amendments to the Tax Code regarding the reduction of customs duties and VAT on the import of equipment for the production and consumption of biomethane that is not produced in Ukraine.

The consumption of petrol and diesel in Ukraine has fluctuated during the last decades. During the period of 2000-2021, the range was within 5.1 - 6.3 Mt/y for diesel. After 2008, the consumption of petrol was reducing to the level of 2.0 Mt/y in 2021. The use of LPG was much lower, though the general trend was towards increase to 1.3 Mt/y in 2021. The total consumption of liquid fuels in the transport sector is approximately correspond to 10 billion cubic meters (bcm) of methane.

In the National Energy and Climate Plan for the period up to 2030, the national indicative target for renewable energy sources in the gross final energy consumption in the transport sector by 2030 is 17.2%. If 17.2% of the liquid fuels used by transport sector are replaced by biomethane, its potential consumption may approximately be at the level of 1.7 bcm.

Similarly, if diesel fuel in agriculture is replaced with a corresponding share of biomethane, the potential agricultural consumption will be 0.22 bcm of biomethane. This volume of biomethane will be sufficient to operate 7.8 thousand tractors similar to NH T6.180 model, with a total cost of about 1.4 billion EUR.

The development of biomethane as a transport fuel in Ukraine presents a significant opportunity to reduce GHG emissions, enhance energy security, and support the transition toward a more sustainable energy sector. However, several regulatory and policy barriers must be addressed to unlock its full potential. The general recommendations outlined in this report provide a basic framework for overcoming these challenges and fostering the growth of biomethane usage in transportation. By implementing these recommendations, Ukraine can establish a strong foundation for biomethane adoption in the transport sector.

Content

Acronyms

AD	Anaerobic Digestion
AFID	Alternative Fuels Infrastructure Directive
AFIR	Alternative Fuels Infrastructure Regulation
BMP	Biomethane potential
CHP	Combined Heat and Power
CMU	Cabinet of Ministers of Ukraine
CNG	Compressed Natural Gas
DGE	Diesel Gallon Equivalents
EVs	Electric Vehicles
ETS	Emissions Trading System
FCVs	Fuel Cell Vehicles
FQD	Fuel Quality Directive
GDP	Gross Domestic Product
GDS	Gas Distribution System
GHG	Greenhouse Gas
GOs	Guaranty of Origin
GTS	Gas Transit/transmission System
HDV	Heavy Duty Vehicles
HFO	Heavy Fuel Oil
LDV	Light Duty Vehicles
LFG	Landfill Gas
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gases
MBT	Mechanical Biological Treatment of waste
MDO	Marine Diesel Oil
MENRU	Ministry of Ecology and Natural Resources of Ukraine
MGO	Marine Gas Oil
MSW	Municipal Solid Waste
NCV	Net Calorific Value
NG	Natural gas
OFMSW	Organic Fraction of Municipal Solid Waste
RES	Renewable Energy Sources
RFNBO	Renewable Fuels of Non-Biological Origin
RNG	Renewable Natural Gas (term used mostly in U.S., equivalent of biomethane)
SAEE	State Agency on Energy Efficiency and Energy Saving
SAF	Sustainable Aviation Fuels
SSSU	State Statistic Service of Ukraine
TSO	Transmission System Operator
VS	Volatile Solid
WWTP	Waste Water Treatment Plant

1. Overview of the CH4 motor fuel market

1.1 General transport sector statistics data

Transportation plays a crucial role in global economies, facilitating the movement of goods, people, and services across different regions. The global transport system can be divided into several key modes, each with unique characteristics, infrastructure requirements, and economic significance. Major modes of transportation include road, rail, air, marine, and pipeline transports. Their structure and key statistics data are presented in Table 1.1.

Table 1.1. Structure and key statistics of the world transport sector

Transportation mode	Key characteristics
Road Transport	• Structure: Includes highways, urban roads and rural roads used by vehicles such as cars, buses, and trucks. • Key Statistics: ○ Accounts for ~75% of global passenger transport. ○ Handles ~70% of global freight transport (by volume). ○ The total length of roads worldwide is estimated at 64 million km. ○ The number of motor vehicles worldwide exceeds 1.4 billion. ○ Leading countries in road networks: USA, China, India.
Rail Transport	• Structure: Includes high-speed rail, freight rail, metro/subways, and conventional trains. • Key Statistics: ○ Global rail network length: ~1.3 million km. ○ Carries about 9% of global freight. ○ Leading countries by rail network: USA (~250,000 km), China (~150,000 km), Russia (~85,000 km), India (~68,000 km). ○ High-speed rail dominates in China (> 40,000 km), Japan, and Europe.
Air Transport	• Structure: Includes commercial aviation, cargo airlines, and private air travel. • Key Statistics: ○ Global commercial fleet: ~30,000 aircraft. ○ Air passenger numbers: ~4 billion annually (pre-COVID-19). ○ Air cargo volume: ~60 million metric tons per year. ○ Leading airports: Atlanta (USA), Beijing (China), Dubai (UAE), London (UK), Tokyo (Japan).
Maritime Transport	• Structure: Includes cargo shipping, passenger ferries, and cruise lines. • Key Statistics: ○ ~90% of world trade is carried by sea. ○ Global merchant fleet: ~100,000 vessels. ○ Leading ports: Shanghai (China), Singapore, Rotterdam (Netherlands), Los Angeles (USA). ○ The Suez and Panama Canals are key global chokepoints.
Pipeline Transport	• Structure: Used primarily for oil, natural gas, and other fluids. • Key Statistics: ○ Total length of pipelines worldwide: over 3 million km. ○ Major pipeline networks: USA, Russia, China, Canada, Middle East. ○ Critical pipelines: Keystone (USA-Canada), Nord Stream (Russia-Europe)*, Trans-Siberian Pipeline.

* does not operate

Fossil fuels dominate the world transport industry, accounting for over **90%** of the sector's energy consumption (Fig. 1.1, 1.2). Petrol, or gasoline[1] (passenger cars, motorcycles, small trucks) and diesel (trucks, buses) are major fuels for the road transport. Fuel used by trucks and buses is 96% fossil fuels in the form of diesel (81%), petrol (11%), and natural gas (3%). Air transport consumes practically 100% aviation kerosene as jet fuel. Fuel use in shipping is virtually 100% fossil fuels in the form of heavy fuel oil (HFO), marine gas oil (MGO), and marine diesel oil (MDO).

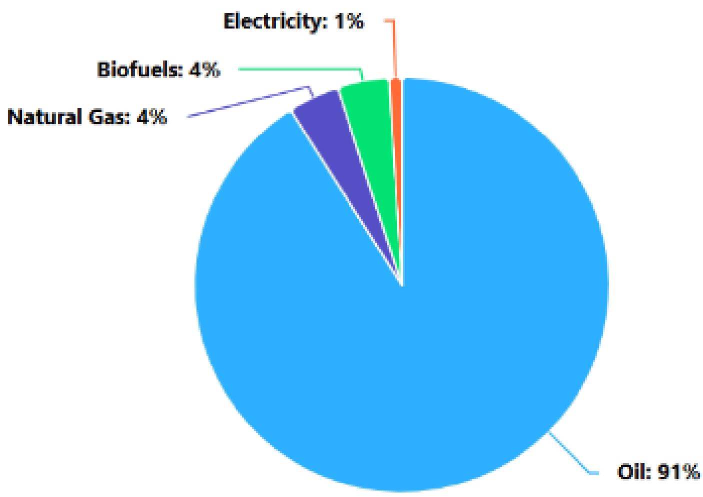
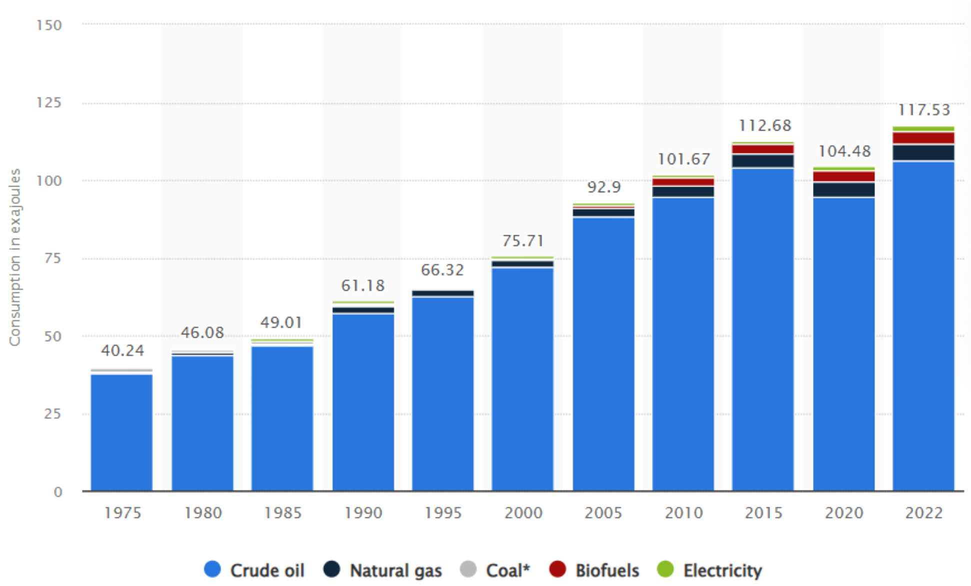


Fig. 1.1. Global energy consumption in transport by fuel, 2022[2].



*Mostly coal used in rail transportation, with slight shares of other sources not elsewhere specified.

Fig. 1.2. Energy consumption in the transportation sector worldwide in select years from 1975 to 2022, by source (EJ)[3]

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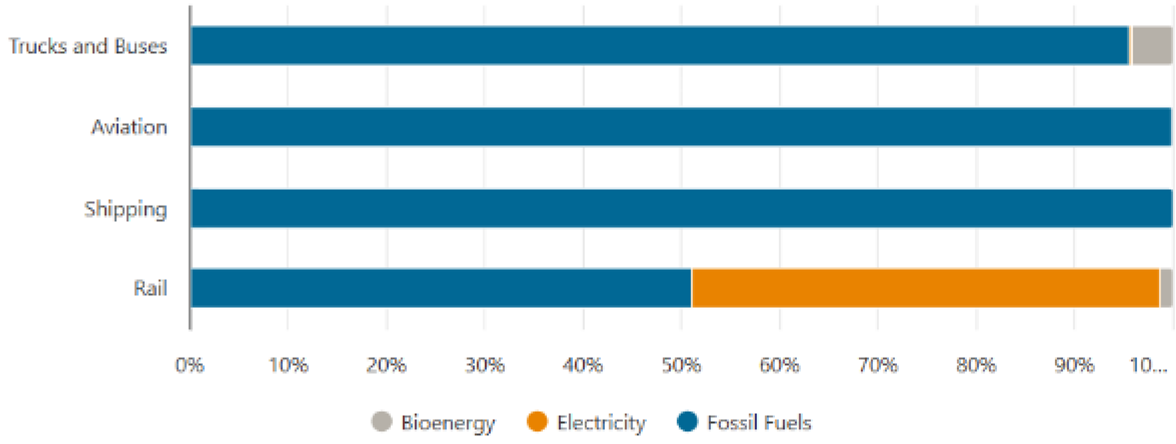
[1] Terms "petrol" and "gasoline" are used as synonyms in the report.
[2] https://understand-energy.stanford.edu/energy-services/energy-transportation#:~:text=Over%2090%25%20of%20transportation%20is,pollutants%20that%20affect%20human%20health.
[3] https://www.statista.com/statistics/1495756/global-transportation-energy-consumption-by-fuel/

The share of **biofuels** in the global energy consumption in transport is only **6%**, bioenergy being mostly used by trucks in road transport (Fig. 1.3). As a result of domination of fossil fuels, transport sector accounts for **~25%** of global CO_2 emissions and **16%** of global greenhouse gas (GHG) emissions. At that, road transport is the major contributor of CO_2 emissions (Fig. 1.4). Thus, it is obvious that one of transport main challenges is **environmental impact.**



Passenger and freight transport is included.

Fig. 1.3. World fuel use by transport mode, 2022

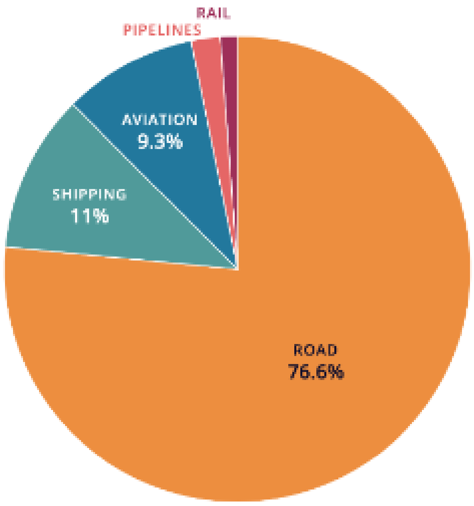


Fig. 1.4. Global CO_2 emissions from transport by sub-sector, 2021[4]

As the world is moving towards sustainability, the transport sector must reduce its carbon footprint by shifting to **low-carbon and renewable** fuels and energy carriers. Current trends in transportation related to this transition include the use of biofuels and biomethane, electric vehicles (EVs), green aviation technologies (e.g., Sustainable Aviation Fuels, hydrogen and electric aircraft), sustainable shipping innovations such as liquefied natural gas (LNG), green methanol, wind-assisted vessels.

Bioethanol, biodiesel and biogas/biomethane are the most promising green fuels for road transport. LNG, besides ships, can be alternative fuel for trucks and some trains. Compressed Natural Gas

[4] https://blogs.worldbank.org/en/opendata/sustainable-transport-livable-future

(CNG) can be used by buses, taxis, and fleet vehicles. Hydrogen may find its usage in fuel cell vehicles (FCVs), hydrogen-powered trains and ships. Electricity is becoming one of the key energy carriers in the transport sector, particularly in urban mobility and high-speed rail. In addition, it may find its usage for short-haul regional aircraft.

It should be noted that short distance travel is the easiest place to decarbonize transportation. Cars, light trucks, and motorcycles account for approximately 60% of energy used in transportation, and 97% of those vehicles run on petrol. Because petrol-powered vehicles are extremely inefficient (less than 1% of the car’s fuel moves the driver), decarbonizing personal vehicles is a priority and opportunity for reaching climate change goals. Electric vehicle use is one of the main ways to achieve this. Long-distance travel via air, maritime, and long-haul road, on the other hand, is harder to decarbonize. Policy can play a big role in driving clean transportation forward[2].

Main **future energy trends** in the world transport are considered to be:

- Increasing deployment of biomethane, including bio-CNG and bio-LNG.
- Expansion of green hydrogen production (electrolysis-based H_2).
- Increased biofuel blending in aviation (SAF).
- Development of solid-state batteries for EVs.
- Hybrid solutions combining fuel cells and batteries for long-haul transport.
- Synthetic fuels (E-fuels) made from CO_2 and renewable electricity.

European transport statistic

In the EU, transport activities accounted for **31%** of the final energy consumption in 2022, which made it the highest consumer of final energy, ahead of households (27%) and industry (25%). Road transport was the largest energy consumer responsible for **74%** of all energy consumption in transport sector, or 10,996 petajoules (PJ) (Fig. 1.5). Water transport accounted for 13% of all energy consumed in transport (1,935 PJ), followed by air (11%; 1,700 PJ) and rail transport (1%; 214 PJ). Compared with 2021, air transport recorded the highest increase in energy consumption, with a striking 57% rise. In 2022, energy consumption levels in air transport were approaching the pre-pandemic figures, following sharp declines in 2020 and 2021.

Gas/diesel oil and motor gasoline remain the leading energy sources in road transport. In 2022, gas/diesel oil (excluding the biofuel portion) was the main source of energy in road transport in the EU, with a 65% share. Motor gasoline (excluding the biofuel portion) followed at 25%, ahead of renewables and biofuels (6%), LPG (liquefied petroleum gases) (2%), natural gas (1%) and electricity (0.3%). The shares of fuels shown in Fig. 1.6 has remained largely stable since 2000, with one notable exception: biofuels. Oil and petroleum products, such as gasoline and diesel, have dominated the sector for many decades. While their consumption began to decline around 2007, this trend reversed in 2014, culminating in their highest consumption level in ten years by 2019.

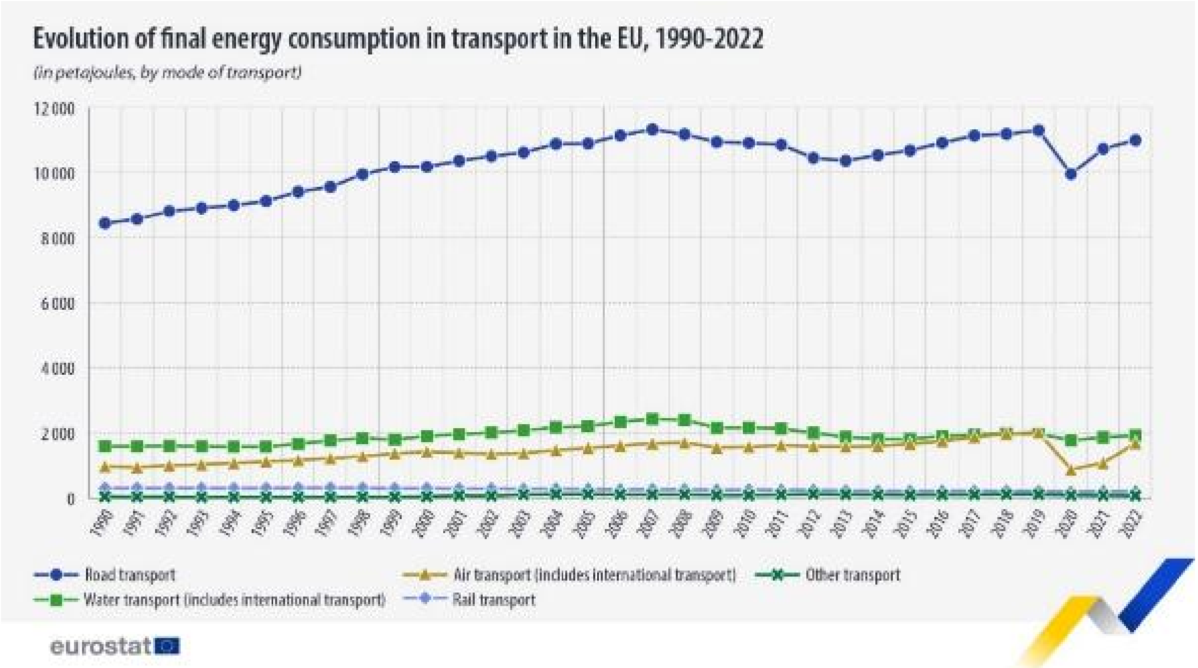


Fig. 1.5. Dynamics of final energy consumption in transport in the EU, PJ[5]

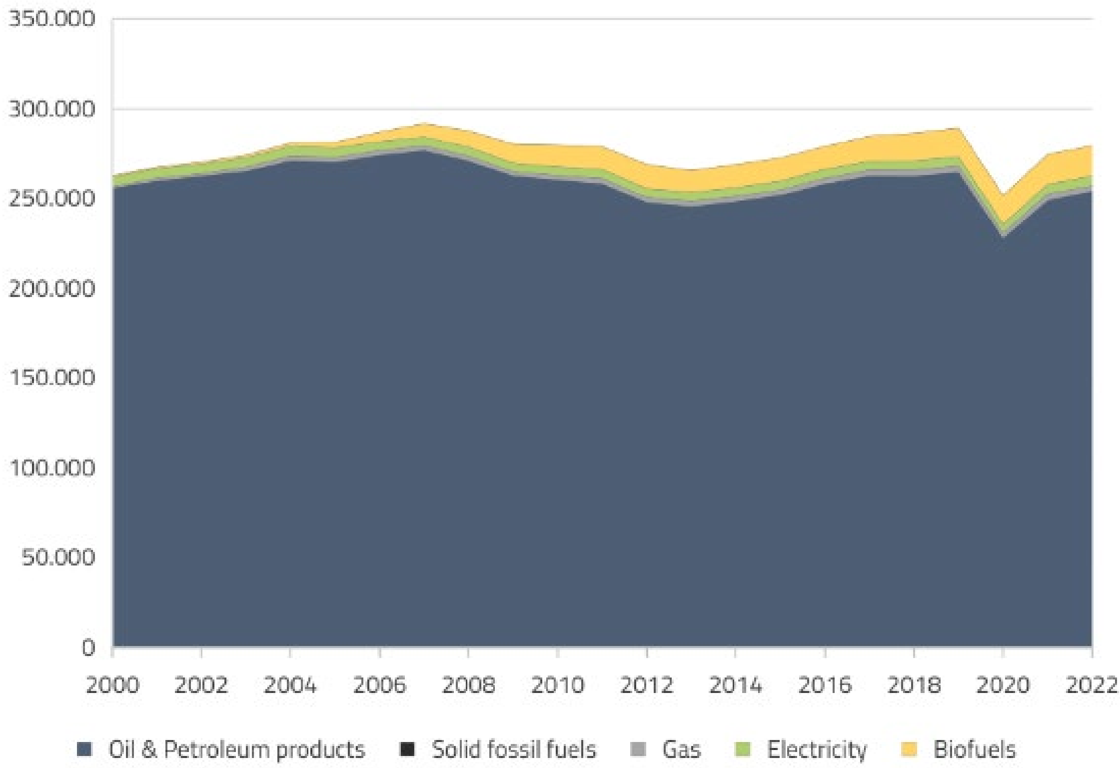


Fig. 1.6. Evolution of the final energy consumption in the transport sector per fuel in the EU-27 (ktoe)[6]

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[5] https://ec.europa.eu/eurostat/web/products-eurostat-news/w/ddn-20241008-1#:~:text=In%20the%20EU%2C%20in%202022,10%20996%20petajoules%20(PJ).

[6] https://bioenergyeurope.org/statistical-reports/

As already mentioned, 65.4% of final consumption in road transport was fuelled by gas/diesel oil in 2022. Motor gasoline was responsible for 25.2%, renewables and biofuels for 6.4%, LPG for 2.0%, natural gas for 0.7%, and electricity for 0.3% (Fig. 1.7). The use of energy products in road transport has changed considerably over the years. In 1990, the main energy source in road transport was motor gasoline at 54.7%, followed by gas/diesel oil at 43.8%. Natural gas accounted for 0.1%, and renewables and biofuels, as well as electricity, were marginal. From 1990 until 2017, there was a steady shift from the use of motor gasoline to gas/diesel oil. Only in recent years motor gasoline has started to gain ground once again. Renewables and biofuels began to increase in 2004, with a steep increase until 2012; it stabilised around 6.5% in 2020-2023. The use of electricity in road transport is almost marginal but has shown a visible increase from 2018 to 2022, with final consumption increasing from 0.05% in 2018 to 0.34% in 2022, a more than six-fold increase.

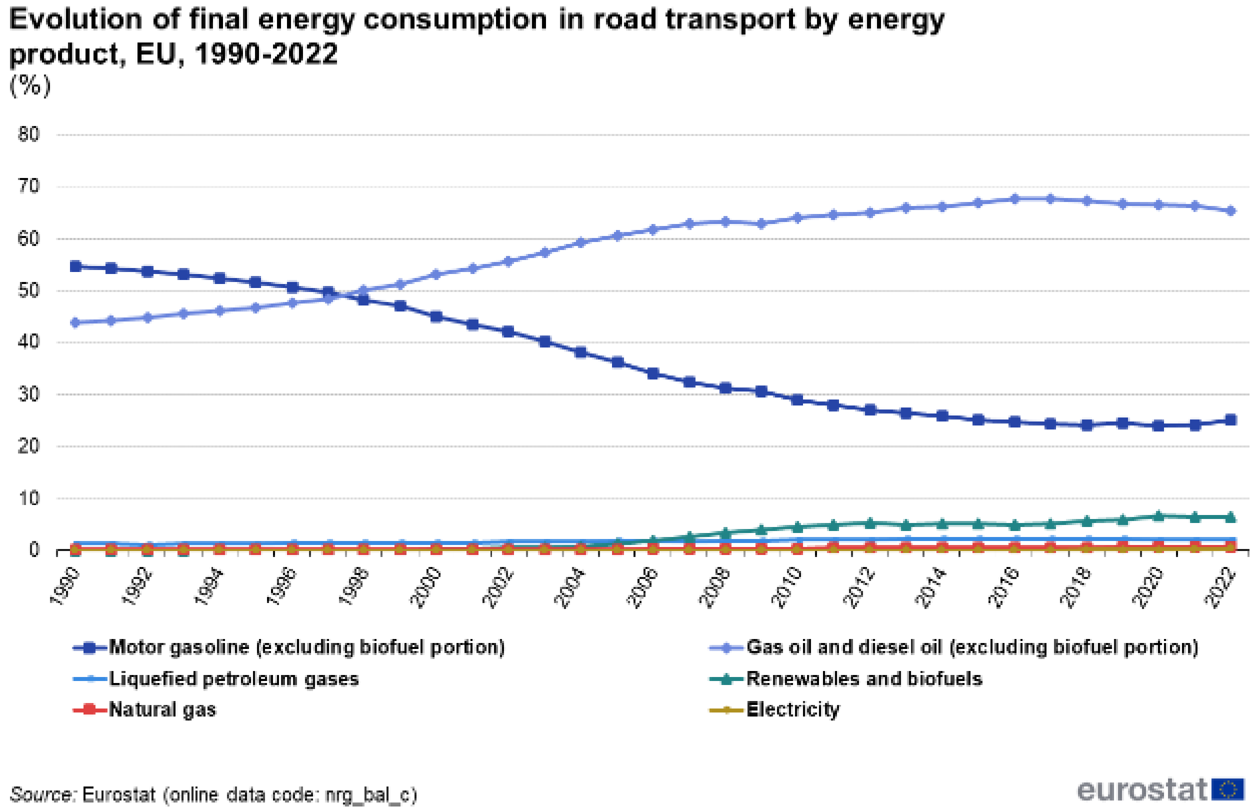

Fig.1.7. Evolution of final energy consumption in road transport by energy product in EU, %[7]

In most EU countries, gas/diesel oil is the primary source of energy for road transport, though there are noticeable differences between the countries (Fig. 1.8). The highest shares were reported in Latvia (80%) and Lithuania (76%), followed by Ireland, Austria, and Spain, each at 74%. In contrast, the lowest shares were recorded in Sweden (45%), Cyprus (46%) and the Netherlands (48%). The share of motor gasoline was highest in Cyprus (50%), the Netherlands (42%), and Malta (36%) in 2022. The lowest shares were reported in Lithuania (13%), Latvia (14%) and Bulgaria (15%).

[7] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Final_energy_consumption_in_transport_-_detailed_statistics#:~:text=As%20seen%20in%20Figure%201,%2C%20and%20electricity%20for%200.3%25.

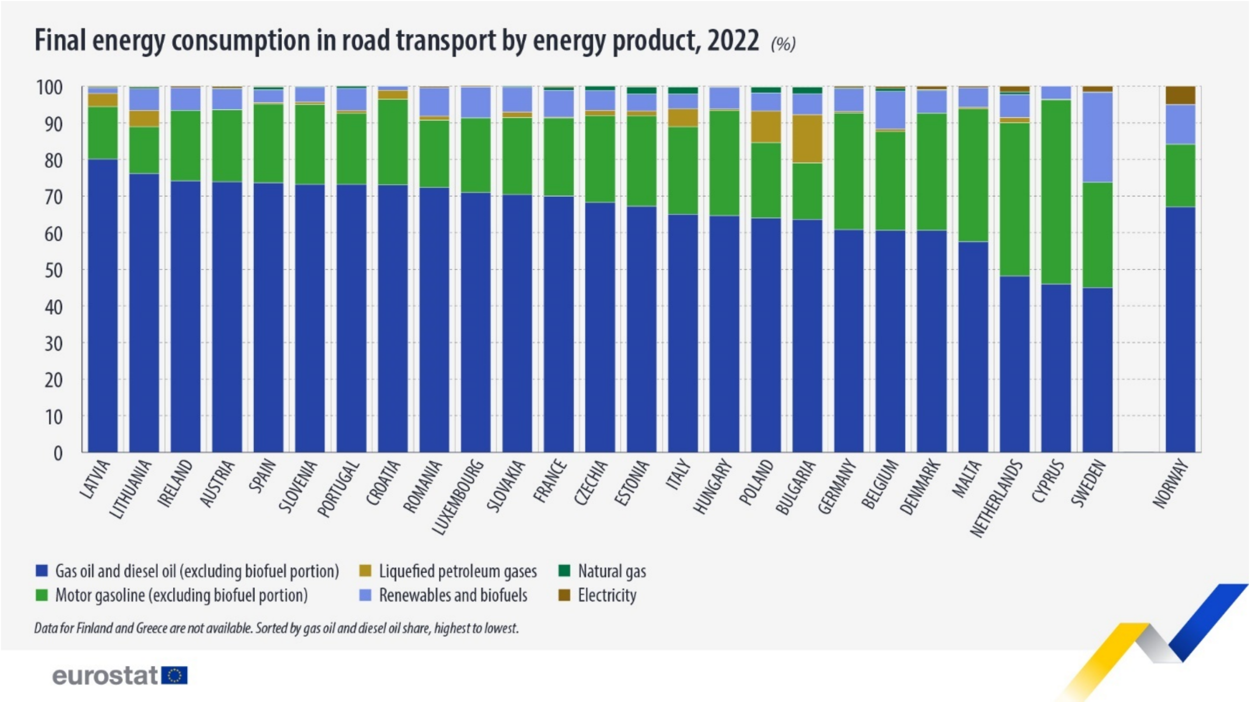

Fig. 1.8. Final energy consumption in road transport by energy product in European countries, %[8]

Currently, transport accounts for **24%** of GHG emissions in the EU despite efficiency improvements and the emergence of climate mitigation policies. That is the third place after fuel combustion by energy users (27.5%) and energy industries (25.6%) (Fig 1.9). Almost three quarters of the EU's transport emissions come from road transport. Existing policy measures are expected to curb a thirty-year upward trend in Europe's transport emissions. Without applying a technology neutral approach, however, the reduction in emissions may not be enough to meet the EU's 2050 climate-neutrality target. **Biomethane provides a sustainable and cost-competitive substitute for fossil fuels, representing one of the few readily available fossil fuel alternatives for long distance and energy intensive transport segments. This makes biomethane a key player in the transition towards a climate neutral economy**.

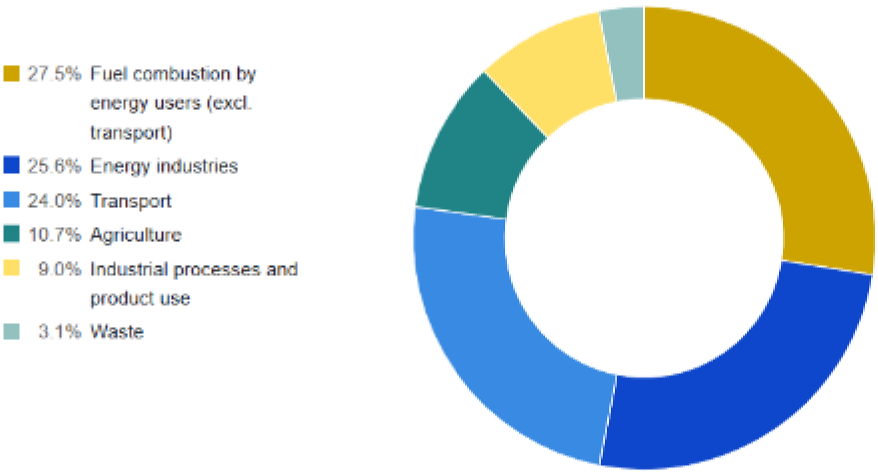

Fig. 1.9. Share of greenhouse gas emissions by source in the EU, 2021[9]

[8] https://ec.europa.eu/eurostat/web/products-eurostat-news/w/ddn-20241008-1
[9] https://ec.europa.eu/eurostat/web/interactive-publications/energy-2024

1.2 Advantages and general prospects for using biomethane as a motor fuel

The use of biomethane in transport has a number of technical, ecological and economic advantages[10] (Fig. 1.10). Compared to diesel and gasoline, it can be burned with relatively low engine wear and low emissions such as nitrogen oxides and particulate matter. CNG vehicles may be equipped with simpler exhaust treatment technology than diesel or gasoline vehicles to meet the same emissions standards. Biomethane has octane number (about 130) that is much higher than that of gasoline (95)[11], which reduces the risk of detonation. All the advantages of biomethane can be used to the greatest extent in engines specially developed for CNG.

Biomethane as transport fuel has low carbon footprint: it can reduce CO_2 emissions by up to 90% compared to diesel and petrol. Biomethane is renewable and sustainable as it is derived from organic waste such as agricultural residues, wastewater sludge, and landfill gas (LFG). Biomethane can be used in compressed (CBG or bio-CNG) or liquefied (LBG or bio-LNG) form in existing natural gas vehicle (NGV) infrastructure, which means that it is *compatible* with existing infrastructure. Usage of biomethane reduces reliance on imported fossil fuels and supports local energy production.

Fig. 1.10. Advantages of using biomethane in transport[10]

Biomethane from energy crops allows the longest driving distance compared to other plant-based vehicle fuels[12] (Fig. 1.11). Today, the focus of biomethane production for vehicle fuel is on using waste materials, by-products and sequential crops.

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[10] https://ibbk-biogas.com/cng-mobility-challenges-and-opportunities-for-biomethane/

[11] Thrän, D., Persson, T., Svensson, M., Daniel-Gromke, J., Ponitka, J., Seiffert, M., Baldwin, J., Kranzl, L., Schipfer, F., Matzenberger, J., Devriendt, N., Dumont, M., Dahl, J., Bochmann, G., 2014. Biomethane - Status and Factors Affecting Market Development and Trade. IEA Task 40 and Task 37 Joint Study. IEA Bioenergy.

[12] https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/Mar/IRENA_Biogas_for_Road_Vehicles_2017.pdf

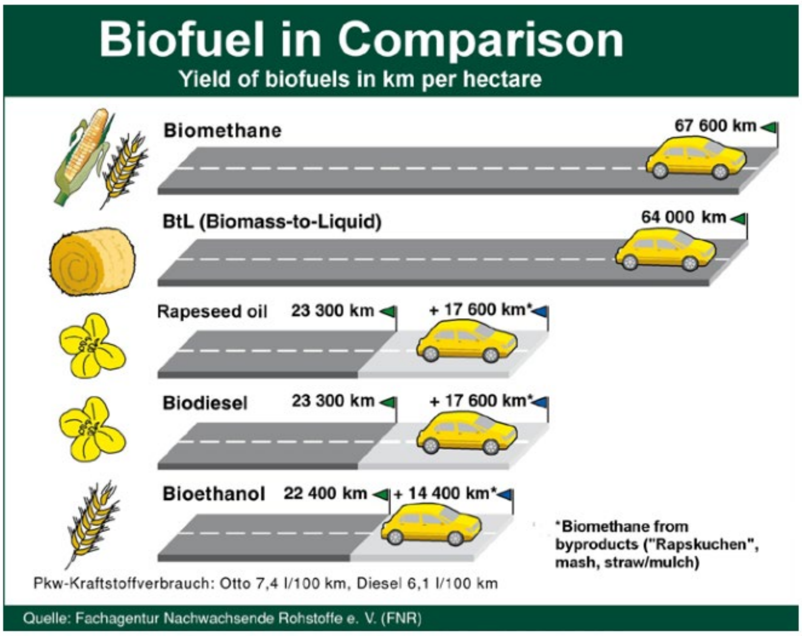

Fig. 1.11. Comparison of biofuels based on their yield in km per hectare[13]

Prospective **key applications** of biomethane in transport include:

- *Heavy-Duty Vehicles:* Biomethane is particularly attractive for buses, trucks, and freight transport due to its high energy density.
- *Maritime Shipping*: Liquefied biomethane is emerging as a low-carbon alternative for ships.
- *Aviation*: While still in early research stages, biomethane-based fuels could be blended with synthetic fuels for aviation.
- *Public Transport & Taxis*: Many cities in Europe and Asia have adopted biomethane-powered buses and taxis.

The EU has set ambitious targets for biomethane integration, with countries like Sweden, Germany, and the Netherlands investing heavily in infrastructure. The U.S. and Canada are expanding biomethane production, especially for use in public transport and freight. China and India are exploring biomethane use in urban transport, supported by waste-to-energy initiatives.

In the future, governments are expected to provide more subsidies, tax benefits, and mandates to promote biomethane in transport. Innovations in anaerobic digestion and upgrading processes may reduce costs and improve efficiency. Private sector participation and public-private partnerships will drive further adoption. Hybrid solutions, such as biomethane-powered fuel cells, could enhance the sustainability of future transport systems.

Based on the above, one can conclude that biomethane holds strong potential for decarbonizing transport, particularly in sectors where electrification is challenging. While challenges remain, advancements in technology, supportive policies, and growing environmental concerns are expected to accelerate its adoption.

However, there are also some **challenges and barriers** in this area. First, while biomethane production is improving in efficiency, the cost remains higher than fossil natural gas. Then, despite growing interest, refuelling stations for biomethane are still limited compared to conventional fuels. Existing policy and regulation gaps, for example**,** inconsistent regulatory frameworks in different

[13] FNR (2007), "Biokraftstoffe im Vergleich (Biofuels in comparison)".

countries, hinder widespread adoption. Dependence of biomethane production on organic waste and agricultural residues limits scalability in some regions.

Biomethane is increasingly being used as a renewable fuel in transport worldwide, particularly in countries focusing on decarbonizing heavy-duty transport and reducing reliance on fossil fuels. **Europe** is a leader in biomethane adoption, with countries like Sweden, Germany, France, and the UK investing heavily in biomethane as a transport fuel. The **U.S.** is one of the largest producers of renewable natural gas (RNG, the American term for biomethane), mainly used in heavy-duty vehicles such as trucks, buses, and refuse collection fleets. California's Low Carbon Fuel Standard (LCFS) has driven significant adoption. **China** is developing biomethane production for transport, focusing on agricultural waste and livestock manure. The government is supporting the expansion of biogas projects for public transport and logistics fleets. The **Indian** government launched the SATAT (Sustainable Alternative Towards Affordable Transportation) initiative, aiming to promote compressed biogas (CBG) for transport. Several CBG plants have been commissioned, supplying biomethane to vehicles. Biomethane is emerging as a complement to bioethanol and biodiesel in **Brazil's** biofuels strategy. The focus is on using biogas from sugarcane processing and landfills to fuel trucks and buses.

Cities worldwide are shifting buses to biomethane-powered fleets, reducing urban emissions. Examples of such cities are London, Stockholm, and Los Angeles. Logistics and freight companies are increasingly adopting biomethane as a lower-emission alternative to diesel. Companies like UPS, Amazon, and DHL are investing in biomethane-fuelled trucks. The shipping industry is exploring biomethane as a fuel, especially as part of the transition to LNG-powered vessels. Some European ports have begun supplying biomethane for shipping. While still in early stages, research is underway on using biomethane-derived fuels for aviation.

The biomethane transport sector is expected to grow significantly in the next decade as more countries set ambitious decarbonization targets and invest in renewable gas infrastructure.

1.3 Current global use of biomethane in transport

The use of biomethane in transport sector is growing globally due to its environmental benefits, regulatory incentives, and potential to decarbonize different sectors of transportation. In the **U.S.**, the production and consumption of RNG (renewable natural gas) is encouraged by several federal and state programs. RNG qualifies as a Cellulosic Biofuel (D3 RINs[14]) under the EPA's Renewable Fuel Standard, making it highly valuable in transportation. Under the Inflation Reduction Act, biogas projects receive tax incentives. Owing to California's Low Carbon Fuel Standard, RNG earns credits based on its carbon intensity, making it highly competitive in the clean fuel market. Oregon Clean Fuels Program & Washington State LCFS provide additional market opportunities. According to the RNG Coalition, there are 250 operational RNG facilities across North America, with nearly 240 more planned or under construction[15]. Class 8 trucks and transit buses are key markets for RNG in the U.S. due to lower operating costs compared to diesel, faster refuelling times vs. battery-electric trucks, the compatibility of RNG with existing CNG and LNG infrastructure. At that, RNG adoption could be limited in light-duty and medium-duty vehicles, which are transitioning to EVs. While electrification and hydrogen will dominate long-term decarbonization, RNG can serve as a critical bridge fuel that

[14] Renewable Identification Numbers (RINs) are credits used for compliance and the currency of epy Renewable Fuel Standard program. D3 RIN corresponds to any biofuel made from cellulose, renewable gasoline, biogas-derived CNG and LNG. https://www.celignis.com/RINs-credits.php#:~:text=Cellulosic%20(D3)%20RINs,baseline%20lifecycle%20greenhouse%20gas%20emissions%E2%80%9D.

[15] https://www.kindermorgan.com/ETV/KM-RNG/Resources/Insights/An-Introduction-to-Renewable-Natural-Gas

reduces emissions today. Investment in infrastructure, policy support, and feedstock innovation will determine RNG's long-term role in transportation.

Projections indicate that **China's** annual biomethane production could reach about 30 Mtoe by 2040[16], with the majority being integrated into the expanding natural gas grid. The Chinese government has implemented policies to promote renewable energy, including biomethane. The 14th Five-Year Plan (2021-2025) emphasizes the development of renewable energy sources, aiming to increase the share of renewables in the energy mix[17]. This plan includes targets for biomethane production and utilization, reflecting the government's commitment to sustainable energy development. Now, biomethane is utilized as a vehicle fuel in China, particularly in CNG vehicles[18]. This application is prominent in public transportation, such as buses and heavy-duty trucks, contributing to reduced GHG emissions and improved air quality. Chinese shipping companies are investing in dual-fuel vessels capable of operating on LNG and biomethane. For example, in November 2024, China launched the world's largest LNG dual-fuel container ship, which exemplifies China's advancements in constructing "maritime green giants"[19]. This strategy aligns with global decarbonization goals and positions biomethane as a viable alternative fuel in the maritime industry. China has abundant biomass resources, including agricultural residues and organic waste, which can be utilized for biomethane production. However, establishing efficient collection and processing systems is essential to ensure a consistent and sustainable feedstock supply.

India generates substantial amounts of biodegradable waste across various sectors, including agriculture, horticulture, animal husbandry, municipalities, sericulture, fisheries, and industries. Collectively, these sources offer a significant potential for biomethane production. Estimates suggest that the country could produce ~125 bcm (billion cubic meters) of biomethane annually, which could meet up to 91% of India's road transport fuel demand[20]. Animal wastes are found to produce the largest volumes of biomethane in the country, followed by agricultural and horticultural residues. Presently, Indian policies encourage an increasing share of natural gas and LPG for transportation and cooking; however, estimations show that biomethane can save substantial quantities of GHG compared to these. This raises the debate on whether natural gas and LPG should be encouraged as transition fuels, and whether undertaking large scale biogas projects could be a better move. Analysing the economics of countrywide biomethane projects will help to answer this and provide data on how replaceable the present-day fuels (especially cooking and transport ones) actually are, in terms of costs. In addition, it may shed light on which of the three end-use scenarios (electricity generation, cooking, and road transportation) is more practical, despite biomethane-to-electricity giving the maximum GHG savings. The Indian government has announced a phased approach to mandatorily blend biomethane into compressed natural gas for transportation and piped natural gas for domestic use. The Compressed Biogas Blending Obligation will be voluntary until the fiscal year

[16] https://www.iea.org/reports/outlook-for-biogas-and-biomethane-prospects-for-organic-growth/the-outlook-for-biogas-and-biomethane-to-2040
[17] https://climate-laws.org/document/14th-five-year-plan-on-modern-energy-system-planning_79df
[18] https://bioenergyinternational.com/first-installtion-envitec-biomethane-bio-cng-filling-station-china/
[19] https://english.shanghai.gov.cn/en-Latest-WhatsNew/20241125/ecc84c4f77d14749b18b91968956e5bd.html?utm_source=chatgpt.com
[20] https://pubs.rsc.org/en/content/articlepdf/2023/se/d2se01028c

2024-2025, becoming mandatory thereafter. The blending targets are set at 1% in 2025-2026, increasing to 5% by 2028-2029[21,22].

As of 2024, **Brazil's** biomethane production is ~1.6 million cubic meters (mcm) per day. Projections indicate an increase to 7 mcm/day by 2029, driven by the expansion of biomethane plants and supportive government policies[23]. The transport sector, predominantly powered by diesel, is a primary market for biomethane. So called "Future Fuels Law" enacted on October 8, 2024, aims to decarbonize Brazil's energy matrix, focusing on transportation and mobility. It includes programs to stimulate biomethane production and consumption, mandates for blending biomethane into natural gas, and incentives for methane-powered vehicles. Starting January 1, 2026, natural gas producers and importers must meet annual GHG reduction targets, beginning with a 1% reduction and potentially reaching up to 10%. Compliance can be achieved through the use of biomethane or the acquisition of Biomethane Guarantee of Origin Certificates[24]. Brazil's National Biofuels Policy, in particular, RenovaBio Program, sets a target to reduce the carbon intensity of fuels in the transport sector by 10% by 2028. Biomethane projects benefit from this program by generating decarbonization credits, which are traded on the B3[25] stock exchange, providing financial incentives for producers[26]. Investments are underway to develop infrastructure supporting biomethane distribution, including the construction of new plants and the establishment of green corridors for heavy vehicles. The government plans to build 25 new biomethane plants across six states, with a total investment exceeding BRL 7 billion, generating at least 6,500 jobs[27].

1.4 Current use and prospects of biomethane in transport in Europe

With the right policy and market conditions, EU biomethane production can achieve the REPowerEU target of **35** bcm by 2030 and could reach **151** bcm by 2050, as reported by EBA. Biomethane has the capacity to play an important role in achieving transport decarbonisation, especially in areas of transport which have difficulty adapting to use other alternative fuels. In road transport, **15** bcm (approx. 154 TWh) would be sufficient to power approximately **20%** of the EU's 2050 heavy-duty fleet with biomethane, according to NGVA Europe; **14** bcm would cover **20%** of the anticipated bio-LNG demand in the shipping sector in 2050, as reported by SEA-LNG. Biomethane also has the potential to decarbonise aviation, a transport segment whose emissions are notoriously hard to abate. The aviation sector is uniquely dependant on gas-turbine engines and jet fuel. Both at industry and at government level, however, biomethane – specifically, sustainable aviation fuel (SAF) derived from biomethane – is being seen as a realistic and viable option for this form of transport. Biomethane can pave the way to a more sustainable future for the aviation sector in the short to medium term; a number

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21 https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1989226#:~:text=Government%20has%20launched%20%E2%80%9CSustainable%20Alternative,use%20along%20with%20Natural%20Gas.

22 https://altfuelscg.com/en/security-policies-standards-and-regulations/indian-government-announces-mandatory-blending-of-biomethane-in-cng-for-transport/?utm_source=chatgpt.com

23 https://revistacultivar.com/news/Biomethane-production-can-decarbonize-heavy-fleet-in-Brazil?utm_source=chatgpt.com

24 https://www.worldbiogasassociation.org/brazil-advances-with-a-new-regulatory-framework-for-biofuels/?utm_source=chatgpt.com

25 B3 is one of the world's largest financial market infrastructure companies, providing trading services in an exchange and over-the-counter environment. https://www.b3.com.br/en_us/b3/about/who-we-are/

26 https://www.iea.org/reports/outlook-for-biogas-and-biomethane-prospects-for-organic-growth/an-introduction-to-biogas-and-biomethane?utm_source=chatgpt.com

27 https://advancedbiofuelsusa.info/brazil-unveils-incentives-to-biomethane-production?utm_source=chatgpt.com

of companies are now investing in projects that aim to produce SAF using biomethane[28]. Existing research studies remark that road transport is likely to absorb a large share of the foreseen EU biomethane production by 2030, while maritime applications are more likely to gain momentum on the long term[29].

Study by the Oxford Institute for Energy Studies[30] show that in Europe, gas-powered transport (both on roads and waterborne) has excellent prospects for the coming decades. The low penetration case projection (maritime transport and road transport) puts the total yearly consumption in 2025 of gas-powered transport at 20.0 bcm; the medium projection is at 34.5 bcm; and the high one at 76 bcm. In all three scenarios biomethane could realistically provide at least **20%** of the total demand in gaseous transport fuel. With the right infrastructure and incentives in place, biomethane producers could quickly make the switch towards the transport sector in only a few years. Beyond 2030, it is likely that the share of biomethane will increase **above 20%** with the aim to fulfil the strategic objective to decarbonise all transport by 2050, alongside with other alternative fuels such as electricity and hydrogen from renewable sources.

Some European experts[31] suggest prioritizing biomethane derived from biowaste, manure, and residual biomass (excluding energy crops) as a part of the fuels for public transport decarbonization in the EU to advance EU decarbonization goals, despite limitations due to resource availability. That is due to the fact that the biomethane opportunity regarding the impacts on climate change strongly depends on the type of the feedstock used: only the biomethane produced from residual mass, such as biowaste or manure, rather than energy crops, reveals to be an interesting alternative in terms of fossil fuels replacement. An enhanced exploitation of biomethane from manure or biowaste would be the most recommended options in the transition towards the net-zero goal, to be integrated by valorising residual biomasses, largely available in many European countries.

Biomethane is one of the most cost-competitive advanced biofuels available today. Europe is the world's leading producer of biogas and biomethane; European production of compressed and liquified biomethane as transport fuel (bio-CNG and bio-LNG) also continues to grow. Furthermore, the EU is leading the way in technology for gas mobility, which has become a mainstream transport solution. Because biomethane consists of the same molecule as natural gas, it is already used as a renewable alternative to fossil fuels in gas vehicles and LNG-powered vessels: little to no change to the existing compressed natural gas (CNG) and LNG-fuelled engines is required. In the same way, biomethane can be directly injected into the gas grid and the already well-developed network of CNG and LNG filling stations. The deployment of biomethane to replace fossil fuels does not require any additional investment of resources and time to develop new infrastructure and technology.

Biomethane is increasingly recognized as a key renewable fuel in Europe's transition toward sustainable transport. Various European countries have implemented policies and projects to integrate biomethane into road, maritime, and even aviation sectors. The EU has set ambitious targets for biomethane production and utilization to replace fossil natural gas in transport. Countries like Sweden, Germany, the Netherlands, and Italy lead in biomethane adoption, particularly in public transport, logistics, and heavy-duty vehicles. The European Green Deal and "Fit for 55" package

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[28] https://www.europeanbiogas.eu/wp-content/uploads/2023/06/EBA_Campaign_FS3_Digital.pdf
https://saf.org.ua/en/news/1698/
[29] https://www.researchgate.net/publication/375689870_The_potential_role_of_biomethane_for_the_decarbonization_of_transport_An_analysis_of_2030_scenarios_in_Italy
[30] https://www.oxfordenergy.org/wpcms/wp-content/uploads/2014/03/NG-84.pdf
[31] https://www.sciencedirect.com/science/article/pii/S2666789424000886?via%3Dihub

emphasize biomethane's role in reducing greenhouse gas emissions. Liquefied biomethane is gaining traction in maritime shipping, offering a viable alternative to LNG.

Biomethane is playing a growing role in decarbonizing EU transport, with a strong presence in public transport, logistics, and maritime applications. Despite challenges such as scaling up infrastructure and feedstock availability, continued policy support and technology advancements are driving adoption. At present, about **3.3** billion m^3 of biomethane is used as transport fuel in Europe[32]. Even if this volume is relatively low compared to gasoline and diesel, it is still a sizeable amount demonstrating mass deployment in parts of Europe. Sweden has the highest share of biomethane in road transport, with a focus on buses and trucks. France has an ambitious roadmap for biogas expansion, with a strong focus on heavy transport. Germany supports biomethane through incentives in its renewable energy and transport policies.

Sweden. At the end of 2023, Sweden operated 71 biomethane plants, which produced 1,542 GWh of biomethane. The Swedish biomethane market is mainly off-grid, comprising several small local and regional grids as well as stand-alone plants with on-site filling stations. Sweden’s gas pipeline infrastructure is limited to the south-western part of the country, while the transport grid is connected to the European gas network via Denmark. The share of biomethane in the south-western grid amounted to 31% including the distribution grids. There is a regional network in Stockholm fuelled with locally injected biogas and LNG that is delivered by ships where the biomethane share was 76% in 2023.

A significant portion of Sweden’s biomethane is transported by road or in local grids as bio-CNG and, to a limited but increasing extent, as bio-LNG. Local and regional gas grids are receiving particular attention in Sweden, as there is an aim to connect industries, cities and biomethane production plants with an LNG terminal on the coast. There are some large industrial operators off-grid that currently use LNG and are interested in using bio-LNG in the future. Both the number of biomethane plants and biomethane production in Sweden have increased steadily over the last decade. The number of plants rose from 47 to 71 between 2011 and 2023, doubling biomethane production from 734 to 1,542 GWh.

Out of 71 Swedish biomethane plants, 13 of them representing about 40% of total biomethane production are connected to the regional network grid in Stockholm or southwestern Sweden, while 58 plants do not have a grid connection and are thus used locally or trucked to filling stations or other users.

Sweden has been actively expanding its network of refuelling stations for biomethane/CNG vehicles, making it easier for fleet operators and public transport providers to switch from fossil fuels. Out of 1,542 GWh of biomethane produced in 2023, 1,210 GWh (78%) was used for road transport. The market for bio-CNG and bio-LNG is well developed, but is highly dependent on *the policy incentives and long-term support systems in place*. There were 231 bio-CNG filling stations and 32 bio-LNG filling stations by the end of 2023. The majority of gas vehicles are passenger cars and light vehicles (LDV), while approximately 10% is represented by HDVs (bus and trucks). Beside the HDV sector, there is also an increasing demand for bio-LNG in industry and also growing interest in the maritime sector.

Europe’s first bio-LNG production plant began operation in Sweden in 2011. At the end of 2023, there were five bio-LNG plants in operation in Sweden, with a total production capacity of over 70 tons bio-LNG/day (315 GWh/year). Another 16 plants are under development and expected to

[32] https://www.europeanbiogas.eu/wp-content/uploads/2019/07/Biomethane-in-transport.pdf

become operational between 2024 and 2026. Sweden's total planned bio-LNG production capacity is 2,264 GWh per year by 2027. This would constitute a considerable share of the European bio-LNG market, as a total of 134 bio-LNG plants are due to start operation in Europe by 2027, with a joint annual production capacity of 21.1 TWh.

Italy. In addition to its successful biogas market, Italy has put considerable effort into developing its biomethane sector. The first biogas plant in Italy to include an upgrading unit was completed in 2012. It was followed in subsequent years by several smaller demonstration plants (< 50 m^3/h of biomethane) without a grid connection. Early in 2018, the Italian government passed a law (Decree of 02 March 2018} to incentivize the production of biomethane. The law was efficient, by the end of 2022, Italy had 48 biomethane plants. In 2023, this number surged, doubling to 96 facilities, making Italy one of the fastest growing biomethane markets in Europe. The biomethane production capacity was 0.71 bcm in 2023. It was mainly originated from different types of agricultural feedstocks and the organic fraction of municipal waste (OFMSW).

The Biomethane Decree of 2 March 2018 encourages the production of biomethane for use in transport. As a result, almost all of Italy's biomethane production is currently used in transport as 'advanced' fuel. In 2023, there were 1,672 CNG filling stations and 166 LNG filling stations. By the end of 2023, in Italy there were eight active biomethane filling stations, including three bio-LNG stations. By the end of 2023, 15 bio-LNG plants were active. Italy's total planned bio-LNG production capacity by 2025 is about 3 TWh per year.

Germany. Both within Europe and worldwide, Germany is the biggest producer of biogas and biomethane. Germany continued to lead the European anaerobic digestion (AD) sector in 2023, with over 11,000 biogas plants (59% of the total number in Europe) and 258 biomethane plants (17% of Europe's biomethane plants).

However, 42% of Europe's biomethane was produced in Germany in 2019; by 2023, its share of European biomethane production had dropped to 25%, primarily because of the faster growth in such countries as France, Italy or Denmark.

German biomethane production began in 2006. Since then, the number of biomethane plants and total biomethane production have grown constantly and, in 2023, Germany reached 258 biomethane-producing units, with biomethane production of over 13 TWh. In 2023, a total of 52 plants were connected to the distribution grid and 106 to the transmission grid. Eight plants are known to have no grid connection: six of these produce bio-LNG on site and the other two produce bio-CNG.

An increasing share of German biomethane is being used as a transport fuel. 1,263 GWh of the biomethane produced in 2023 was used in the transport sector, representing 10% of the total production in that year. In comparison, 380 GWh of biomethane was used in transport in 2017 and 884 GWh in 2020.

There is particular interest in the production of bio-LNG in Germany. Like Italy and the Netherlands, Germany is expected to become a leader in European bio-LNG production. Thus far, Germany has focused on larger liquefication plants that purchase biomethane via GOs. However, plans for new bio-LNG projects in the German market include a variety of plant sizes and on-site liquefaction technologies coupled with the valorization of biogenic CO_2, which is incentivized by the German government.

By the end of 2023, Germany was home to 16 active bio-LNG plants, and 10 further plants are at different stages of development. Germany's total planned annual bio-LNG production capacity by 2025 is 8.1 TWh. This constitutes a considerable share of the European bio-LNG market, which is expected to reach a total production capacity of 19.2 TWh/year by the end of 2025.

Overall, there are more than 800 CNG filling stations and 159 LNG stations in Germany. It is estimated that >60% of all CNG stations provide a CNG/bio-CNG blend or up to 100% bio-CNG. At least 29 LNG filling stations provide blends of LNG/bio-LNG and more than five LNG stations offer 100% bio-LNG.

Norway. In recent years, biomethane has also generated increasing interest, particularly regarding its use in heavy-duty vehicles, as well as in industry and shipping. Norway's combined biogas and biomethane production in 2023 was 740 GWh. Most of the biomethane produced in Norway is used in the transport sector: in 2023, this amounted to 431 GWh, or 74% of total biomethane production. The country is home to eight bio-LNG filling stations and a further 29 bio-CNG filling stations.

Norway has always been a pioneer of bio-LNG production in Europe, inaugurating its first bio-LNG production plant in 2012. It was home to the biggest bio-LNG production site in Europe until 2021. The plant in question has a bio-LNG production capacity of 120 GWh/year and is planning to double this capacity in the coming years.

Finland. Both the biogas and the biomethane sectors are well developed in Finland. Although Finland currently primarily produces biogas, it is expected that most of the country's upcoming new projects will upgrade their biogas to biomethane. Significant and consistent growth of Finnish biomethane sector has taken place over the last decade, with the number of biomethane plants rising from one in 2011 to 25 in 2023. Finnish biomethane production increased significantly within the same time frame, finally reaching 242 GWh by 2023.

Off-grid biomethane production plays a vital role in Finland, as only the southern part of the country has a gas grid. For the same reason, LNG terminals are also central to Finland's gas infrastructure. Of the 25 active biomethane plants in Finland, five are connected to the grid and 20 plants operate off-grid.

In general, Finnish energy and climate strategies promote biogas for use as a transport fuel. There is specific investment support for filling stations and for converting passenger cars to run on gas. Procurement subsidy for heavy-duty gas vehicles was launched in December 2020. Since 2022, biomethane has been part of the national biofuel delivery obligation along with other types of transport fuels, which is expected to provide a stable outlook for increasing biomethane production and use up to 2030.

In 2023, all biomethane produced was used in the transport sector. Of the biomethane plants active by the end of 2023, 23 plants produce bio-CNG on-site and one plant produces bio-LNG on-site. In total, 82 bio-CNG filing stations, and 18 bio-LNG filling stations are operational in Finland.

Estonia. By 2023, Estonia had a portfolio of eight biomethaneplants in operation. The first two plants were commissioned in 2018, a further three plants were completed between 2020 and 2021, and three more plants began operating during 2022 and 2023. Six of the eight plants are in fact biogas-CHP plants that have switched to biomethane production.

Estonian biomethane production reached 152 GWh in 2021, 168 GWh in 2022 and 211 GWh in 2023. This growth is expected to continue following the development of new biomethane plants in 2023 and beyond. The total biomethane production capacity in 2023 was 3,035 m^3/h.

All biomethane in Estonia is compressed to form bio-CNG for use in the transport sector. The bio-CNG is used by passenger vehicles, public transport, buses and trucks. Across the country, five municipalities run their public transportation either fully or partly on bio-CNG. There are 29 bio-CNG filling stations in Estonia, two bio-LNG filling stations has already been set up in the country.

Estonia aims to reach a share of 14% renewable transport fuels; this is equivalent to 340 GWh of biomethane and is primarily to be achieved using domestic biomethane production. Given the current biomethane production of 211 GWh, this means the country has achieved 60% of its goal. In addition, biomethane is used as a biofuel for public buses andthere is investment support for the construction of CNG stations with a requirement to sell biomethane.

Data regarding use of Bio-CNG and Bio-LNG in selected countries in 2023 are shown in table 1.2.

Table 1.2. Bio-CNG and Bio-LNG in selected countries in 2023[33]

Country	Biomethane used in transport, GWh	Percentage of total biomethane used in transport	Bio-CNG/bio-LNG filling stations	CNG and LNG filling stations
Sweden	1,210	78%	263/20	Unavailable
Italy	7,363	100%	5/3	1,672/166
Germany	1,168	11%	>60/29	980/159
Norway	431	75%	29/8	Unavailable
Finland	242	100%	67/11	70/14
Estonia	211	100%	29/2	Unavailable

The Netherlands. Biomethane production in the Netherlands first took off in 2013. The number of biomethane plants grew rapidly between 2016 and 2023, rising from 21 active biomethane plants to 81. 2,930 GWh of biomethane was produced in the Netherlands in 2023, most ofwhich originated from agricultural waste (52%), industrial organic waste (16%) and organic municipal waste(12%). Of the 81 biomethane plants in the Netherlands,72 are known to be connected to the gas grid. The remaining nine plants do not have a grid connection.

The Netherlands produces bio-CNG as well as bio-LNG. According to the EBA database, there are four bio-LNG and four bio-CNG plants in operation.Over 170 public filling stations in the Netherlands offer bio-CNG.

[33] EBA 2024. “European Biogas Association Statistical Report 2024”. Brussels, Belgium, December 2024.

2. European regulation and policy, support schemes in European countries

2.1 Key EU Policies and Directives

The transition toward low-carbon transport fuels is a key priority within the European Union as part of its broader strategy to achieve climate neutrality by 2050. In this context, natural gas and biomethane have been identified as viable alternatives to conventional fossil fuels, particularly in the transport sector. Several EU Directives provide the regulatory framework for the adoption and promotion of these fuels, which are further supported by national policies. Through a combination of binding targets, financial incentives, and infrastructure development mandates, the EU seeks to accelerate the transition from conventional fossil fuels to cleaner and more sustainable fuel options. The key directives shaping the policy framework for natural gas and biomethane in transport include the Renewable Energy Directive (RED III) – Directive (EU) 2023/2413, the Regulation on the Deployment of Alternative Fuels Infrastructure (AFIR) – Regulation (EU) 2023/1804, and the Fuel Quality Directive (FQD) – Directive 2009/30/EC. Each of these legislative measures plays a vital role in defining national-level strategies and support mechanisms for the deployment of low-emission transport fuels across member states.

The **Renewable Energy Directive (RED III)**[34]**,** which came into force in October 2023, supersedes RED II and introduces more ambitious targets for renewable energy in transport. Under RED III, EU member states must ensure that at least 29% of the energy used in the transport sector comes from renewable sources by 2030, effectively doubling the target previously set under RED II (14%). This directive strengthens the sustainability criteria for biomethane production, ensuring that only biofuels and biogases produced from waste-based or advanced feedstocks qualify for incentives. By promoting the injection of biomethane into existing gas grids, RED III facilitates its integration into the EU's energy system, reducing dependency on fossil natural gas. The directive also introduces specific mandates for advanced biofuels and renewable fuels of non-biological origin (RFNBOs), such as synthetic methane, positioning biomethane as a key component in decarbonizing transport.

Replacing the now-repealed Alternative Fuels Infrastructure Directive (AFID) – Directive 2014/94/EU, the **Regulation on the Deployment of Alternative Fuels Infrastructure (AFIR) – Regulation (EU) 2023/1804**[35] was adopted to ensure the uniform and binding deployment of refuelling infrastructure for alternative fuels, including CNG, LNG, and biomethane. Unlike AFID, which provided policy guidance, AFIR sets legally binding infrastructure targets that member states must meet. It requires the construction of publicly accessible refuelling stations for CNG, LNG, and biomethane along the Trans-European Transport Network (TEN-T) corridors, ensuring seamless access to alternative fuels across Europe. Furthermore, AFIR encourages biomethane integration into existing natural gas infrastructure, ensuring that renewable gas can be distributed through the same refuelling stations used for fossil natural gas.

Another key regulatory measure shaping the EU's transport fuel strategy is the **Fuel Quality Directive (FQD) – Directive 2009/30/EC**[36], which was updated in 2016 to reflect new sustainability and emission reduction requirements. The consolidated FQD (2016) sets fuel quality standards and emissions criteria for all fuels used in transport across the EU. One of its primary objectives is to ensure that all fuels, including natural gas and biomethane, comply with strict environmental performance standards. The updated FQD introduces several key elements that directly impact the

[34] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32023L2413&qid=1699364355105
[35] https://eur-lex.europa.eu/eli/reg/2023/1804/oj/eng
[36] https://eur-lex.europa.eu/eli/dir/2009/30/oj/eng

use of natural gas and biomethane in transport. The Directive permits and encourages the blending of biomethane with natural gas, thereby facilitating the gradual transition to renewable methane-based transport fuels. Fuel suppliers are required to monitor and report the carbon intensity of the fuels they place on the market, ensuring compliance with GHG reduction targets. The Directive also ensures that fuels supplied within the EU remain compatible with existing vehicle and refuelling infrastructure, promoting seamless adoption of low-carbon fuels.

In response to the Russian invasion of Ukraine, the EU launched the **REPowerEU initiative**[37]. This plan significantly impacts the natural gas and biomethane sectors, as it aims to reduce dependency on Russian fossil fuels and accelerate the transition to renewable energy sources. The initiative sets a target to increase EU biomethane production to 35 billion cubic meters (bcm) per year by 2030, significantly boosting the availability of renewable methane for transport applications. REPowerEU strengthens financial support for biomethane projects, aligning with RED II (III), AFIR, and FQD to create a more resilient and diversified energy supply for transport.

2.2 National Legislation and Support Schemes

Figure 2.1 outlines two main policy approaches for supporting renewable energy and biofuels, including biomethane for transport: direct subsidies and market-oriented mechanisms. Direct subsidies focus on production and investment support. Production support is provided through feed-in tariffs and premiums, which offer stable revenue for biomethane producers. Contracts-for-difference ensure price stability, making biomethane more competitive. Investment support, mainly through capital grants, reduces the initial costs of biomethane production facilities and refuelling infrastructure.

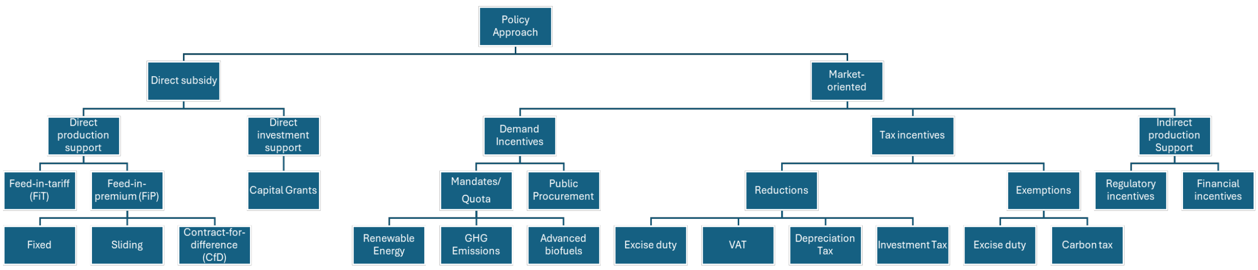

Fig. 2.1. Policy Approach for Renewable Energy and Biomethane Support in Transport[38]

Market-oriented mechanisms stimulate demand and financial viability. Mandates and quotas require a minimum share of renewable energy in transport, driving biomethane adoption, while public procurement policies encourage the use of biomethane in government and public transport fleets. Tax incentives, such as reductions in excise duty, VAT, and investment taxes, lower costs for biomethane producers and consumers. Exemptions from carbon and excise taxes further enhance biomethane's competitiveness against fossil fuels. Indirect production support includes regulatory incentives that streamline grid and refuelling infrastructure integration, along with financial incentives such as low-interest loans and credit guarantees.

[37] https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/repowereu-affordable-secure-and-sustainable-energy-europe_en
[38] European biogas Association.

By combining direct subsidies with market-driven measures, this policy framework facilitates the large-scale adoption of biomethane in transport. It ensures financial stability for producers, encourages infrastructure development, and creates a competitive environment where biomethane can replace fossil fuels, contributing to emissions reduction and energy independence.

Sweden. Sweden has committed to achieving net-zero greenhouse gas emissions by 2045, with significant milestones in the transport sector, including a 70% reduction in emissions from domestic transport (excluding domestic air services) by 2030 compared to 2010 levels[39]. Sweden's approach to biomethane development is based on tax exemptions, investment subsidies, and the promotion of biogas infrastructure. In alignment with the European Union's Regulation (EU) 2023/1804 on the deployment of alternative fuel infrastructure, Sweden is working towards ensuring that alternative fuel refuelling stations, including those for biomethane, are available at regular intervals along major transport corridors (TEN-T).

Tax exemptions. Under the Swedish Energy Tax Act, biomethane was fully exempt from energy and carbon taxes when used as a transport fuel. At the end of 2022, the state aid approval for the Swedish tax exemption in 2021-2030 for biogas and bio-LPG for transport or heating was revoked by an EU General Court ruling[40]. Following this annulment, the European Commission initiated an in-depth investigation to reassess the compatibility of these tax-exemption schemes with EU State aid rules. Subsequently, on October 23, 2024, the Commission concluded that the Swedish tax exemption schemes for non-food-based biogas and bio-propane are in line with EU State aid rules, reaffirming their contribution to renewable energy development and alignment with EU climate objectives[41,42].

Investment support for biomethane infrastructure. The Climate Step (Klimatklivet) program is Sweden's primary investment support mechanism for biomethane production and infrastructure development. Managed by the Swedish Energy Agency, the program provides **direct financial support** for projects that reduce greenhouse gas emissions, including those focused on biogas upgrading, biomethane refuelling stations, and industrial biomethane applications. Since its launch in 2015 to 2023, Klimatklivet support for biogas-related investments in Sweden reached roughly 40 million euros[43]. The funding **covers up to 40% of the investment costs** for projects that contribute to Sweden's fossil-free transport goals. Eligible initiatives include new biomethane production plants, particularly those using agricultural waste and residues, expansion of biomethane refuelling infrastructure, upgrading existing biogas plants to increase biomethane output, and injection of renewable gas into the national grid.

Integration of biomethane into the natural gas grid. The Swedish Gas Act provides the legal framework for the regulation of Sweden's gas market, including provisions for biomethane grid injection. The law establishes rules for third-party access to the gas grid, ensuring that biomethane producers can inject renewable gas into the national gas distribution system under non-discriminatory conditions. A key amendment to the Swedish Gas Act in 2023 introduced incentives for biomethane producers to increase grid injection rates. The Swedish Energy Markets Inspectorate revised tariff structures, **lowering grid access fees** to facilitate the connection of smaller biogas plants to the national grid. Additionally, the amendment established clearer technical and safety standards for

[39] https://fossilfrittsverige.se/en/the-journey/chapter-1/
[40] Landwärme GmbH v European Commission (Case T-626/20).
[41] https://task37.ieabioenergy.com/wp-content/uploads/sites/32/2024/10/IEA_Bioenergy_T37_CountryReportSummary_2024.pdf
[42] https://www.bioenergy-news.com/news/eu-approves-swedish-tax-exemption-schemes-for-non-food-biogas-and-bio-propane/
[43] https://www.sciencedirect.com/science/article/pii/S0959652624032086

biomethane injection, ensuring that renewable gas meets the same quality requirements as natural gas before injection to the grid[44].

Sweden has also leveraged **public procurement policies** to expand the use of biomethane in municipal and regional transport fleets. The government expanded public sector requirements for biomethane-powered transport, mandating its use in state-owned vehicle fleets.

Production support[45] for biogas generated from manure has been in place since 2015, at up to 40 €/MWh, and is intended to reduce methane emissions from manure. The new long-term production support scheme for biomethane, up to a maximum of 0.3 euro/kWh and an additional maximum of 0.15 euro/kWh for liquified biogas, has been effective since 1st July 2022 and can be combined with production support for manure-based biogas.

Sweden's biomethane support schemes have proven to be comprehensive and effective, combining fiscal incentives, regulatory frameworks, and infrastructure investments to accelerate the transition to a fossil-free transport system. Sweden's approach effectively aligns with national climate goals and EU regulations, making it a strong model for promoting biomethane adoption.

Italy. The Italian government employs multiple support mechanisms to enhance the use of renewable energy in transportation, primarily through mandatory quotas for biofuels and support for biomethane production and investment.

Mandatory Quotas. The primary support mechanism for renewable energy in the transport sector in Italy is the **biofuel-blending obligation** for fossil fuel suppliers, including biomethane[46]. To comply with this obligation, suppliers can either blend the mandated share of biofuels directly or acquire equivalent rights through the purchase of Biofuel Certificates (CICs). A mandatory quota for advanced biofuels, produced from non-food feedstocks such as agricultural and industrial wastes, residues, lignocellulosic materials, and algae, has been established. The Ministerial Decree of 16th March 2023 revised the biofuels mandate, introducing sub-targets for gasoline blending and biofuels used independently of fossil fuels. Additionally, the decree allows compliance through renewable fuels of non-biological origin (RFNBO) and recycled carbon fuels (RCF). These provisions took effect in 2023, with compliance verification beginning in 2024.

All biofuels released for consumption in Italy must adhere to sustainability criteria set by the RED III and the Fuel Quality Directive. Compliance is ensured through certification under the National Certification Scheme, voluntary schemes approved by the European Commission, or agreements with third countries. Failure to meet obligations incurs a penalty of €750 per missing CIC[47].

Support for biomethane on the market. Producers of advanced biomethane injected for transport use can opt to sell their biomethane to GSE[48] (Gestore dei Servizi Energetici) at a price equal to the market rate minus 5%, plus a premium linked to CIC values (€375 per CIC). Alternatively, producers can sell directly, receiving only the CIC premium. This incentive scheme applied to plants commissioned between 2018 and 2023 and was also available to existing biogas plants converted to advanced biomethane production during this period. The total supported biomethane volume under

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[44] https://www.government.se/government-agencies/the-swedish-energy-markets-inspectorate/

[45] Support schemes for biogas and biomethane in Sweden, EBA.

[46] This requirement is regulated by Legislative Decree 3rd March 2011, n. 28, and Ministerial Decree (MD) 10th October 2014, with significant updates introduced by MD 16th March 2023, n. 107.

[47] https://www.ieabioenergy.com/wp-content/uploads/2024/12/CountryReport2024_Italy_final.pdf

[48] https://www.gse.it/servizi-per-te/rinnovabili-per-i-trasporti/biometano/ Gestore dei Servizi Energetici (GSE) is Italy's state-owned company responsible for promoting and managing renewable energy and energy efficiency incentives. It operates under the supervision of the Italian Ministry of Environment and Energy Security.

the scheme was 1.1 bcm per year, financed by fuel suppliers. However, access to this scheme concluded on December 31, 2023[49].

Biomethane producers for transport can now benefit from **investment support** aims to support investments in new biomethane production plants and the conversion of existing biogas plants, with €1.92 billion in available funding[50]. The support mechanism includes **investment grants** that cover up to 40% of incurred costs for constructing new biomethane plants or converting biogas plants and **operating incentive** that provides a support tariff applied to net biomethane production[51]. Biomethane injected into the natural gas grid under this scheme can be used in the transport sector or for heating purposes in all sectors except for electricity generation.

Italy has developed a robust support framework for renewable energy in transportation, with a strong focus on biomethane. The mandatory biofuel blending quotas ensure a stable market for biofuels, while the CIC certificate system provides financial incentives for compliance. The country has also invested significantly in biomethane production, offering both market-based incentives (via GSE) and direct investment support for new and upgraded plants.

Germany. Germany's policy landscape for biomethane in transport is shaped by a combination of national legislation, EU directives, and strategic climate action plans aimed at reducing GHG emissions and advancing renewable energy sources. The key policy instruments guiding these developments include[52]:

- Federal Emission Control Act, which sets regulations for emissions reduction in the transport sector and requires fuel companies to reduce their carbon footprint.
- Biofuel Sustainability Ordinance, ensuring that biomethane and other biofuels meet sustainability criteria.

GHG Quota System: Germany has established progressive GHG emission reduction targets for the transport sector, increasing from 9.25% in 2024 to 25% by 2030. To further drive decarbonization, the government has set minimum targets for advanced biofuels: 0.4% in 2024, increasing to 2.6% in 2030 for advanced biofuels.

A significant regulatory framework for promoting GHG reductions is outlined in §§ 37a–g of the Federal Emission Control Act[53]. Since 2015, these provisions have replaced the Biofuel Quota Act, shifting the regulatory focus from an energy-based quota—where a minimum quantity of biofuels had to be supplied based on energy content—to a GHG savings requirement. Germany now operates a **fuel quota system based on GHG reduction**. Biomethane's contribution to these savings is financially incentivized, allowing producers to market their fuel's GHG reductions. Depending on the emissions balance and quota pricing, revenues between 5 and 15 euro cents per kWh are achievable.

Tax Exemptions. Biomethane used as a transport fuel benefits from a complete exemption from energy and CO_2 taxation. Additionally, lorries powered by natural gas (CNG/LNG) have been **exempt from toll charges** since January 1, 2019, with this exemption extended until December 31,

[49] https://www.clearygottlieb.com/-/media/files/alert-memos-2022/new-italian-incentives-for-biomethane.pdf
[50] The Ministerial Decree of 15th September 2022 implements the measure 'Development of biomethane according to criteria for promoting the circular economy' under Mission 2, Component 2, Investment 1.4 of the National Recovery and Resilience Plan.
[51] https://www.dentons.com/en/insights/guides-reports-and-whitepapers/2022/november/14/new-incentives-for-the-biomethane-sector
[52] https://www.ieabioenergy.com/wp-content/uploads/2024/12/CountryReport2024_Germany_final.pdf
[53] Support schemes for biogas and biomethane in Germany, EBA.

2023[54]. However, since no distinction was made between biomethane and natural gas, there was no increased demand for biomethane. The German government is now considering the introduction of a GHG-based toll system, which could further impact the demand and marketability of biomethane in the transport sector.

Germany is emerging as a key player in bio-LNG production within Europe. Future bio-LNG projects in Germany are expected to feature a range of plant sizes and on-site liquefaction technologies, enhancing flexibility and efficiency. Additionally, these projects incorporate **biogenic CO_2 valorization,** a process incentivized by the German government to promote carbon capture and utilization, further strengthening the sustainability of bio-LNG production.

Recent efforts have prioritized the expansion of compressed natural gas infrastructure along key mid- and long-distance road networks to accelerate the transport sector's decarbonization. Additionally, the federal government actively supports the adoption of liquefied natural gas for heavy-duty transport and maritime applications, promoting cleaner fuel alternatives in these sectors. Germany's support schemes and tax incentives make biomethane an attractive and viable fuel for transport. Continued policy enforcement and market incentives will be key to achieving GHG reduction goals by 2030 while maintaining biomethane's economic competitiveness.

Finland. Finland has implemented a range of policy measures aimed at reducing greenhouse gas emissions in the transport sector and promoting the adoption of alternative fuels, including biomethane. These policies align with national climate targets and EU regulations, supporting the transition to a low-carbon transport system. The key support mechanisms for biomethane include the biofuel delivery obligation, tax reductions, and investment support. Finland's energy and climate strategies strongly advocate for biomethane, particularly as a transport fuel, reinforcing its role in the country's transition to sustainable mobility. In 2023, all biomethane produced was used in the transport sector.

Biofuel delivery obligation. Finland has set a legally binding target for biofuels to account for 34% of all fuels used in road transport by 2030, a measure expected to prevent around 3 million tons of CO_2 emissions in that year. However, the government has revised its biofuel distribution obligation multiple times. As of January 2024, the target was adjusted to 13.5%, down from the previously planned 28%[55]. Further revisions for 2025–2027 are anticipated under the current Government Programme. Starting in 2022, biomethane is a part of the national biofuel delivery obligation, along with other types of biofuels[56,57].

Tax reductions. Since 2022, sustainable biomethane has been subject to a **lower excise duty rate** compared to natural gas in the transport sector.

Investment support is available for the development of new renewable energy production facilities, including newly built biomethane plants for both industrial and agricultural applications. The level of aid varies based on the type of investor and the degree of innovation in the project. Approximately €35 million was allocated for subsidies between 2022 and 2023, with an additional €10 million for 2024.

Specific investment support is provided for filling stations and for converting passenger cars to run on gas. A **procurement subsidy** for heavy-duty gas vehicles was launched in December 2020. To further support fleet decarbonization, Finland introduced purchase subsidies for alternative-fuel

[54] https://www.toll-collect.de/en/toll_collect/rund_um_die_maut/meldungen/detailsseite_news_8768.html?utm_source
[55] https://www.ieabioenergy.com/wp-content/uploads/2024/12/CountryReport2024_Finland_final.pdf
[56] Support schemes for biogas and biomethane in Finland, EBA.
[57] EBA Statistical Report, 2024.

commercial vehicles: €2,000–14,000 per gas-powered truck and €2,000 per gas-powered van. Between 2022 and 2024, a total of €12 million was allocated to these subsidies.

Latvia. Although Latvia **has not yet introduced formal legislation on biomethane production**, progress in the sector is accelerating. The country's first biomethane-producing biogas plant began operations in 2020, using the fuel internally for its vehicle fleet. By 2023, biomethane production reached 14 GWh, with all of it utilized for transport purposes. In 2024, six new biomethane production facilities became operational, with a combined annual capacity of approximately 30 million cubic meters.

Several draft versions of biomethane legislation are currently under discussion among industry stakeholders. The Latvian Biogas Association has proposed a **mandate requiring natural gas operators to replace 10% of fossil natural gas with biomethane by 2030**. The Ministry of Economics has endorsed this proposal and is now working on a strategic plan to implement the target[58].

Lithuania. Lithuania has set an ambitious target to produce at least 950 GWh of biomethane by 2030, as outlined in the Ministry of Energy's strategic plan. The National Energy Independence Strategy Action Plan also provides financial support for producing biomethane from agricultural and non-communal waste, with regulatory measures aimed at increasing biomethane usage in transport.

Regulatory and market incentives. To facilitate the growth of renewable fuels in the transport sector, the Lithuanian government has introduced a **binding obligation** for natural gas suppliers. By 2025, at least 4.2% of the total energy content of natural gas sold must come from biomethane or other renewable gas sources. This percentage is set to increase annually, reaching 16.8% by 2030. Although gas supplier obligations will take effect in 2025, since 2022, biomethane supplied to the transport sector has been eligible to receive fuel statistics units through the Guarantees of Origin system, which can also be used to meet liquid fuel obligations.

Investment and financial support measures. Lithuania has introduced several financial support mechanisms under the National Climate Change Programme to accelerate biomethane adoption:

1) 45–65% investment support for biomethane and biogas production.
2) 40% investment support for purchasing vehicles powered by electricity, CNG, LNG, bio-CNG, bio-LNG, or hydrogen, as well as funding for alternative fuel infrastructure development.
3) 60% investment support to increase the use of renewable fuels in urban and suburban public transport, particularly promoting electric, CNG, and LNG-powered vehicles.

These policy measures are designed to strengthen Lithuania's biomethane market, enhance energy security, and support the country's transition toward a low-carbon transport system[59].

Estonia. Estonia is actively advancing its biomethane production through a combination of direct and indirect support measures.

In 2017, the Ministry of Economic Affairs and Transport implemented a **premium scheme** to bridge the price gap between natural gas and biomethane based on biomethane certification. The Estonian Transmission System Operator, Elering, issues a biomethane certificate to producers, verifying that the gas has been produced from renewable energy sources. The premium is linked to the natural gas price on the Baltic Natural Gas Spot (GET Baltic), and the amount changes periodically. Biomethane

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[58] EBA Statistical Report, 2024.
[59] EBA Statistical Report, 2024.

producers receive a premium for consumption in the transport sector of €100 per MWh, minus the average natural gas market price during the previous month on GET Baltic and secondary revenues.

Investment grant. Launched in 2024 and managed by the Estonian Environmental Centre, this program has a €19 million budget and aims to increase biomethane production by at least 4 million cubic meters. The first round of applications took place in August 2024, attracting eight applications, of which four projects have already been awarded grants, as reported by the Estonian Biogas Association.

Estonia has set a renewable transport fuel target of 14%, equivalent to 340 GWh of biomethane, with a focus on domestic production. As of 2024, the country has already achieved 60% of this target, with 211 GWh of biomethane production. Biomethane is widely used as a biofuel for public transportation, and **investment support is available for CNG refuelling stations**, with a requirement that these stations must sell biomethane. The support covers up to 35% of CAPEX costs, with a maximum of €350,000 per project. The same regulation provides investment support for biomethane public buses, covering up to 30% of the total investment cost, with support ranging from €400,000 to €4,000,000, depending on the project.

In August 2022, the Ministry of Rural Affairs introduced **investment aid for bioresource valorization**. This scheme aims to assist companies in their green transition by increasing the economic value of bioresources. It supports the construction of facilities for the treatment and pre-treatment of bioresources, including biomethane plants. Aid can cover up to 50% of eligible investment costs, with a minimum of €500,000 and a maximum of €5,000,000 per application.

Additional policy measures supporting biomethane in transport in Estonia include **tax exemptions** for biomethane used as a transport fuel[60].

2.3 Efficiency of the support schemes for biomethane in EU countries

Support schemes for biomethane in some EU countries, and evaluation of their efficiency are shown in table 2.1.

Table 2.1. Support schemes for biomethane in some EU countries, and evaluation of their efficiency

Country	Support Measures	Efficiency
Sweden	- Tax Exemptions - Investment Support (Klimatklivet program) covering 40% of project costs - Production support (up to 0.3 €/kWh for biomethane, additional 0.15 €/kWh for bio-LNG) - Mandatory biomethane infrastructure expansion - Public procurement requirements for biomethane vehicles - Grid injection incentives	- Comprehensive approach combining fiscal, regulatory, and infrastructure support. - Effective in increasing biomethane production.
Italy	- Mandatory blending quotas for biofuels - Biofuel Certificates (CICs) as compliance mechanism	- Strong financial measures with investment grants and operating incentives.

[60] EBA Statistical Report, 2024.

Country	Support Measures	Efficiency
	- Investment support (€1.92 billion available) - Support tariff for injected biomethane - Market-based incentives for biomethane producers	- Well-structured quota system. - High biomethane integration but reliance on continued financial mechanisms.
Germany	- GHG Quota System (increasing from 9.25% in 2024 to 25% by 2030) - Tax exemptions for biomethane - Bio-LNG production incentives - GHG-based toll system under consideration - Infrastructure investment for CNG/LNG fuelling stations	- High financial attractiveness for biomethane through quota system. - GHG quota provides a direct revenue stream for biomethane producers. - Strong policy alignment with EU targets.
Finland	- Biofuel delivery obligation (34% by 2030, revised to 13.5% in 2024) - Tax reductions for sustainable biomethane - Investment grants for biomethane production and transport - Fleet decarbonization subsidies (€12 million allocated)	- Strong focus on biomethane in transport. - Investment and tax support encourage production and adoption.
Latvia	- No formal legislation yet - Biomethane production incentives under discussion - Proposal for a 10% biomethane blending target by 2030	- Limited legal framework, creating uncertainty. - Recent production growth signals potential.
Lithuania	- Binding obligation for gas suppliers (4.2% biomethane in 2025, rising to 16.8% by 2030) - Investment support (45–65% of project costs) - Grants for alternative fuel infrastructure - Public transport support (60% investment for gas-powered vehicles)	- Clear targets and strong financial incentives. - Well-structured subsidy program.
Estonia	- Premium scheme for biomethane price stabilization (€100/MWh minus gas market price) - Investment grant (€19 million for new biomethane plants) - Mandatory biomethane use in public transport - CAPEX support for refuelling stations and biomethane buses - Bioresource valorization support (up to €5 million per project)	- Effective price stabilization mechanism. - Strong incentives for biomethane in public transport.

After analyzing the support schemes in Sweden, Italy, Germany, Finland, Latvia, Lithuania, and Estonia, several common features emerge. Below are the most widespread and efficient policies that have proven successful in stimulating biomethane adoption in transport:

1. **Investment support for biomethane production and infrastructure.** Every country provides financial aid for constructing new biomethane plants or upgrading existing biogas facilities. Support levels range from 40% (Sweden, Italy, Lithuania) to 65% (Estonia, Lithuania) of capital expenditures.

2. **Tax incentives or exemptions for biomethane as a transport fuel.** Most countries (Sweden, Germany, Finland, Estonia) offer partial or full exemptions from energy and CO_2 taxes for biomethane. In some cases (e.g., Germany, Sweden), these exemptions are time-limited and subject to EU state aid rules.

3. **Mandatory biofuel blending or quota systems.** Italy, Germany, Finland, Lithuania, and Estonia impose binding quotas for biomethane or biofuels in the transport fuel mix. These quotas require fuel suppliers to blend biomethane with natural gas or compensate via certificate trading (Italy's CIC system, Germany's GHG Quota).
4. **Infrastructure expansion for refuelling stations and grid integration.** Sweden, Italy, Germany, and Estonia have mandatory biomethane infrastructure requirements, ensuring refuelling stations for CNG/LNG and biomethane are available along key transport routes. Some countries (Sweden, Estonia) provide CAPEX grants to support new biomethane refuelling stations.
5. **Public transport and heavy-duty vehicle subsidies.** Several countries (Sweden, Germany, Finland, Estonia, and Lithuania) provide subsidies for biomethane-powered buses and trucks to decarbonize fleets. Estonia and Finland have purchase incentives for gas-powered commercial vehicles (e.g., €2,000–14,000 per truck in Finland).

3. Production and logistics of biomethane as gaseous motor biofuel

3.1 General remarks

Today, the use of biogas as motor fuel is practiced in the form of compressed biomethane (bio-CNG) and liquefied biomethane (bio-LNG). It is also known about promising research of direct use of biogas in dual fuel systems of agricultural machines[61,62].

Biomethane has characteristics similar to natural gas and can therefore be a complete substitute for transport powered by natural gas. Biomethane can be used in maritime transport, heavy-duty vehicles, private cars, public transport, and agricultural machinery.

The use of methane in transport has a number of technical, environmental and economic advantages[63,64,65] (**Fig. 1.10**). As compared to diesel and petrol, it can be burned with relatively low engine wear and low emissions, such as nitrogen oxides and particulate matter. Vehicles powered by methane can be equipped with simpler exhaust gas cleaning technology than diesel or petrol cars to meet the same emission standards. Biomethane has a significantly higher octane number (approximately 130) than petrol (95) [66], which reduces the risk of detonation. All the advantages of biomethane can be used to the greatest extent in engines specially designed for CNG.

Logistic chains for the use of biofuel from biomethane in transport can be as follows:

1. Supply of compressed biomethane to the GTS or GDS → Production of bio-CNG (200...250 bar) at existing or new gas filling stations connected to the GTS or GDS → Refuelling of the vehicles running on CNG
2. Liquefaction of biomethane to bio-LNG → Transportation of bio-LNG in mobile tanks → Refuelling of road, rail, water and air transport running on LNG
3. Compression of biomethane to bio-CNG (200...250 bar) → Transportation of bio-CNG in mobile containers → Refuelling of motor vehicles running on CNG
4. Transportation of biomethane (3...10 bar) through a separate gas pipeline → Production of bio-CNG (200...250 bar) at existing or new gas filling stations → Refuelling of motor vehicles running on CNG

If using biogas in dual fuel systems, without bringing it to the quality of biomethane, the logistic scheme can be similar to schemes 3 and 4.

There is a clear tendency to increase the capacity of Bio-LNG plants. In Europe, bio-LNG production plants had an average capacity of 51 GWh/year in 2022 and this is expected to rise to 157 GWh/year by 2027.

As of the end of 2023, there were 59 active *liquefied biomethane* (Bio-LNG) plants in Europe [67]. This number was expected to grow rapidly in 2024 (+46 plants), 2025 (+14 plants) and to continue to grow at high speed thereafter, with more than 134 bio-LNG plants scheduled to be ready by 2027. The

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[61] https://www.eurekanetwork.org/project-database/?search=BIOGASDRIVE&country=ukraine&dateStart=&dateEnd=

[62] https://www.researchgate.net/publication/331932367_Evaluation_of_Using_Biogas_to_Supply_the_Dual_Fuel_Diesel_Engine_of_an_Agricultural_Tractor

[63] https://ibbk-biogas.com/cng-mobility-challenges-and-opportunities-for-biomethane/

[64] https://www.vdik.de/en/topics/alternative-drivetrains/lng-for-commercial-vehicles/

[65] http://ukravtogaz.com/perevagi-metanu

[66] Thrän, D., Persson, T., Svensson, M., Daniel-Gromke, J., Ponitka, J., Seiffert, M., Baldwin, J., Kranzl, L., Schipfer, F., Matzenberger, J., Devriendt, N., Dumont, M., Dahl, J., Bochmann, G., 2014. Biomethane - Status and Factors Affecting Market Development and Trade. IEA Task 40 and Task 37 Joint Study. IEA Bioenergy.

[67] European Biogas Assosiation Statistical Report 2024. https://www.europeanbiogas.eu/

combined bio-LNG production capacity by the end of 2025 is expected to reach 21.1 TWh per year, taking into account both active plants and forthcoming projects.

According to the Natural Gas Vehicles Association (NGVA) of Europe, there are currently over 15,000 LNG-powered vehicles operating on European roads. This number was expected to grow to 280,000 by 2030, representing at least 25% of the market share. This fleet of vehicles will require approximately 100 TWh of fuel (LNG and Bio-LNG) in 2030. In October 2023, 707 LNG stations in Europe and European Free Trade Association (EFTA) countries were listed (**Fig. 3.1**). The countries with the largest number of LNG fuelling stations are Germany with 183, Italy with 143, Spain with 97, and France with 79 LNG stations. The size of the fuelling network intended for road transport appears to be steadily growing.

These figures show that a significant share of Bio-LNG consumption can already be expected in the coming years.

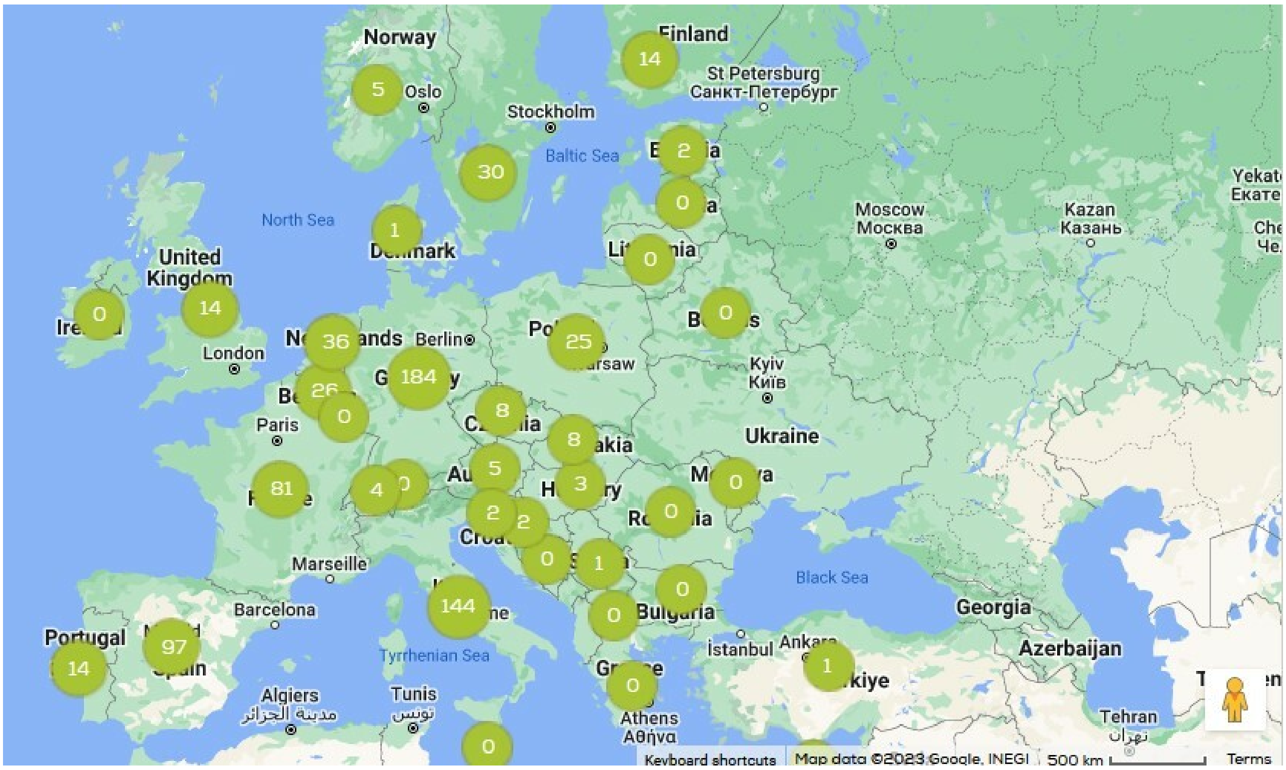

Fig. 3.1. Map of LNG stations across Europe in 2023[68]

Alongside the anticipated expansion of the bio-LNG market, the production of bio-CNG in Europe is also steadily rising. Out of the 1,478 biomethane plants active in Europe at the end of 2023, a total of 142 plants were known to compress biomethane on-site to generate bio-CNG. In addition to on-site bio-CNG production facilities, which are physically connected to biogas upgrading units, bio-CNG can also be obtained directly at filling stations by extracting gas from the gas grid and procuring biomethane via Guarantees of Origin (GOs) mechanism.

NGVA (CNG-EU, 2018) estimates the current number of CNG vehicles in EU-28 in about 1.3 million light duty vehicles, 17,000 buses and coaches and 9,000 trucks. In the same study, the number of methane fuelled trucks in 2030 are set in 480,000 units, thus with an expected average year on year new sales of about 36,000 units (**Fig. 3.2**).

[68] https://iifiir.org/en/news/news-web-nov-dec-2023-over-700-lng-stations-for-road-transport-in-europe

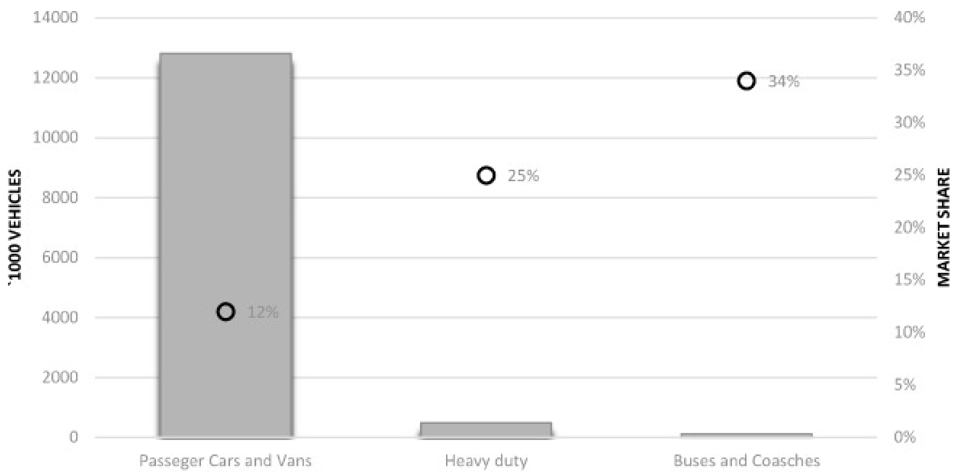

Fig. 3.2. Elaboration from NGVA's gas vehicle roadmap towards 2030 (NGVA Europe, 2018)[69].

An extensive grid of CNG and LNG filling stations already operates in Europe, and a large number of them are also ready to handle biomethane for supply either through physical delivery or using the GOs mechanism. There were 4,175 CNG stations and 700 LNG stations in operation in Europe as of the end of September, 2023[70].

Although not all European countries closely monitor the number of CNG and LNG filling stations that also offer bio-CNG and/or bio-LNG, the EBA estimated that there were approximately 1,898 *filling stations* with bio-CNG and 123 with bio-LNG in 2021[71].

Italy and Germany, together with the Netherlands, are expected to become the leading countries in the production and use of bio-LNG in the coming years. A total of 10 European countries are currently active in the bio-LNG production market, namely: Belgium, Denmark, Finland, France, Germany, Italy, the Netherlands, Norway, Sweden and the United Kingdom.

Gas (CNG and LNG) filling stations are not as dominant as their liquid fuel counterparts, but they are more available than refuelling installations for other alternative fuels such as electric and hydrogen-powered transport.[72]

Over the coming years, multiple solutions will be needed to cover different market needs and transport scenarios. Electric trucks might find applications in some cases up to 500 km use, but other alternatives will be needed in the long term to cover long-haulage transport needs. Heavy-duty road transport is technically hard to electrify because it requires powerful engines able to cover long distances while carrying a heavy payload. This demands specific and highly efficient powertrains supported by an adequate amount of onboard energy.

To operate a 40-ton truck for over 1,000 km, an electric truck would require a 6.4 tonne battery with today's best technology, while the same distance can be covered with approximately 280 kg (620 litres) of (bio)-LNG.[73]

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[69] Prussi, M., Padella, M., Conton, M., Postma, E. and Lonza, L., Review of technologies for biomethane production and assessment of Eu transport share in 2030, JOURNAL OF CLEANER PRODUCTION, ISSN 0959-6526, 222, 2019, p. 565 - 572, JRC113690. https://www.sciencedirect.com/science/article/pii/S0959652619306808?via%3Dihub

[70] https://lngprime.com/europe/european-network-of-lng-stations-hits-new-milestone/93294/

[71] https://www.europeanbiogas.eu/SR-2022/EBA/

[72] EBA (European Biogas Association) (2016) Biomethane in transport https://www.europeanbiogas.eu/wp-content/uploads/2019/07/Biomethane-in-transport.pdf

[73] EBA (European Biogas Association) (2022) Fuelling clean mobility with bio-LNG https://www.europeanbiogas.eu/wp-content/uploads/2022/05/BioLNG-report-2022.pdf

3.2 Biogas upgrading with compression to bio-CNG

Raw biogas from agricultural raw materials usually contains 50-65% CH_4, 35-50% CO_2, as well as up to 1% volume of other gases, in particular hydrogen sulphide H_2S, ammonia NH_3, oxygen O_2, nitrogen N_2, aromatic volatile hydrocarbons, others micro impurities, and water vapour. Oxygen and nitrogen enter the biogas partly with the input raw materials, as well as when air is supplied to the sub-dome space of the bioreactor for the process of biological desulfurization of biogas.

Raw biogas is not suitable for direct energy use, including as automobile fuel, since impurities can cause corrosion of metals in equipment, lead to the formation of unwanted deposits on surfaces, as well as overtime emissions of harmful substances into the atmosphere. Therefore, raw biogas is purified, and the process of purification and upgrading can take place in several stages, depending on the method of energy utilization of biogas and compliance with the defined quality standards (see **Fig. 3.3**).

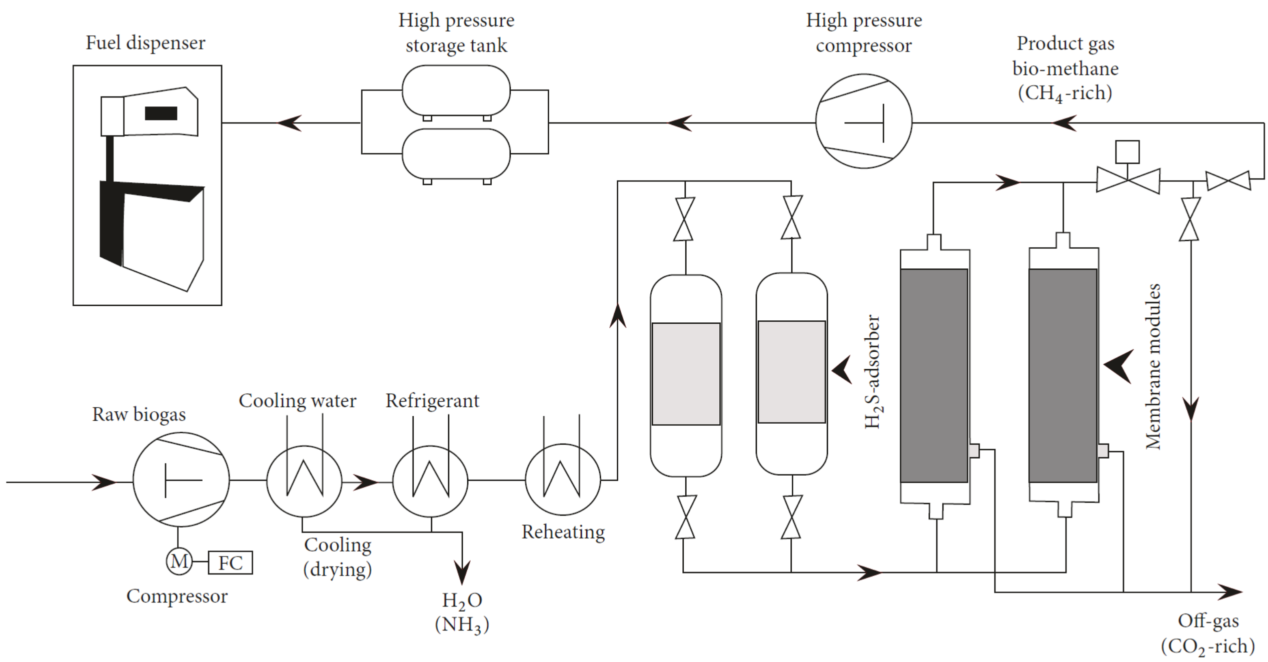

Fig. 3.3. Schematic diagram of total bio-CNG process and vehicle fuelling method[74]

There are at least 6 main technologies for upgrading of biogas to biomethane, which use the processes of absorption, adsorption, filtration and cryogenic technologies (**Table 3.1**). Modern biogas upgrading facilities allow obtaining biomethane with a CH_4 content of 97-99%.

All technologies presented in **Table 3.1** are commercial and used in practice. The choice of technology may depend on the required capacity of biogas upgrading, the method of utilization and requirements for biomethane and CO_2 and other conditions.

After upgrading, the biomethane is compressed to the pressure required for its further transportation to the consumer or direct use at the filling station (usually in the range of 25-35 MPa).

[74] https://doi.org/10.1155/2017/4385295

Table 3.1. The main production characteristics of biogas upgrading technologies

Parameter	Water scrubber	Organic physical scrubber	Amine scrubber	PSA	Membrane separation	Cryogenic separation
Physical process of CO_2 removal	Absorption by water	Absorption by organic solvent	Absorption by amines	Adsorption on the surface	Filtration	Cryogenic technologies
Technology productivity range, m^3/h of biomethane	200-1200	300-1500	400-2000	300-800	50-500	no data
Typical methane content in biomethane, % vol.	95.0-99.0	95.0-99.0	>99.0	95.0-99.0	95.0-99.0	99.0
Share of captured methane, %	98.0	96.0	99.96	98.0	80-99.5	98-99.9
Electricity consumption, kWh/m^3 of biomethane	0.3-0.9	0.49-0.67	0.05-0.27	0.29-1.0	0.14-0.26	no data
Demand for thermal energy and temperature level	–	<0.2 kWh/m^3 of biogas, 70-80°C	0.5-0.75 kWh/m^3 of biogas, 120-160°C	—	—	–

Reciprocating compressors are mainly used to compress natural gas and biomethane for the production of CNG (bio-CNG) (**Fig. 3.4**).

Fig. 3.4. CNG compressor from Minnuo [75]

The compressor type used is the multi-stage reciprocating piston compressor. Compressor size commonly ranges from 20 to 200 kW. The design of the CNG compressor resembles the high pressure air compressor but with some important differences. Discharge pressures of 25 to 35 MPa preclude the use of the multi-stage reciprocating piston compressor. Suction pressures are site specific and dependent on the operating pressures of the local gas utility distribution pipeline. Suction pressures can range from inches water column to 7 MPa. Most often pressure regulation and metering is

[75] https://mncompressor.com/gas_compressor/cng-compressor/

supplied by the gas utility providing stable suction pressures to the compressor. To minimize energy consumption, CNG compressor manufacturers configure compressors specific to the application and suction gas pressure available.

Logistic, refuelling stations, and car demand

Both diesel and gasoline cars can be *equipped* with compressed biomethane supply units. Many car manufacturers today already have specialized CNG vehicles in their model ranges. For example, Mercedes-Benz[76] produces models of cars, commercial vehicles and trucks running on CNG. Various CNG models are also offered by Fiat, Skoda, Seat, Opel, Ford, Audi, Renault, Iveco, Scania, Volvo, Neoplan and others. Models of methane-powered agricultural machinery, such as New Holland[77] and Massey Ferguson tractors, are also on the market.

There are 3 main types of technologies for using biomethane as motor fuel, namely:

- **Specialized vehicles with methane-only engines.** The special gas engine is a spark-ignition (Otto) engine adapted to run on methane, which allows you to get the benefits of high-octane fuel. Such engines can use both bio-CNG and bio-LNG, the latter is vaporized before injection.
- **Dual-fuel vehicles with spark-ignition engines running on methane and gasoline.** Biomethane and gasoline are supplied to the engine by separate systems. As a rule, such cars start running on gasoline, and when the required engine temperature is reached, they switch (automatically or manually) to the use of methane.
- **Vehicles with diesel engines of the dual type, running on methane and diesel fuel.** These cars run mostly on methane, but use some diesel fuel to aid in ignition.

Compressed biomethane can be used as a car fuel in the same way as compressed natural gas, and therefore is a full-fledged substitute of natural gas. For use as a fuel, biomethane is compressed to at least 200 bar[78] and are filled in *cylinders (tanks)* installed on the vehicles.

Compressed biomethane (15°C, 200...250 bar) has an energy content of 9064 MJ/m^3, what is 275 times more than that of uncompressed biomethane, but it is 3.97 times less than that of diesel fuel, 3.53 times less than in gasoline and 2.34 times less than in bio-LNG[79]. 3.6 litres of bio-CNG (15°C, 250 bar) are obtained from 1 m^3 of biomethane (15°C, 1.01325 bar). Biomethane compression from 1 to 200 bar requires 2-3% of the biomethane energy equivalent.

In the absence of a gas grid near the biomethane plant capable of receiving the required amount of biomethane, a reasonable option would be to transport compressed biomethane (250 bar) by *mobile containers* (**Fig. 3.5**) to the nearest existing gas filling station or to a special filling station for bio-CNG. Such containers are intended for both transportation and storage of gas in pressurised form. The container can include from 8 to 12 high-pressure gas cylinders of 250 kgf/cm^2, which allows transporting from 5443 to 9261 m^3 (0ºC, 101.325 kPa) of biomethane.

The advantage of a special new gas filling station can be its location in the most suitable place, with guaranteed consumption by consumers, for example, on a highway or in the logistics hub of a large agricultural enterprise. Biomethane can be delivered to the existing or a new gas station, if appropriate and possible, through a separately laid gas pipeline.

[76] https://cngeurope.com/natural-gas-vehicles/mercedes-benz/
[77] https://agriculture.newholland.com/eu/en-uk/equipment/products/agricultural-tractors/t6-methane-power
[78] Compressed natural gas pressure standard at CNG filling stations in Ukraine
[79] 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. Ammenberg, J; Murphy, J.D. (Ed.) IEA Bioenergy Task 37, 2021:12.

Fig. 3.5. Containers for storage and transportation of compressed natural gas[80]

Filling stations with compressed biomethane can be of three types described below[81].

Fast-filling station (Fig. 3.6): These stations are best suited for retail situations where vehicles arrive randomly and need to fill up quickly. All public CNG stations have a fast-fill option. Fast-fill stations receive fuel from a local utility line at a low pressure and then use a compressor on site to compress the gas to a high pressure. Once compressed, the CNG moves to a series of storage vessels so the fuel is available for a quick fill-up. CNG can also be delivered via dispensers alongside gasoline or other fuel dispensers. CNG at fast-fill stations is often stored in the vessels at a high service pressure (30 MPa) so the dispenser can deliver it to a vehicle quickly. The dispenser uses sensors to calculate pressure and measure the number of gasoline gallon equivalents (GGEs) delivered to the tank, taking temperature into account.

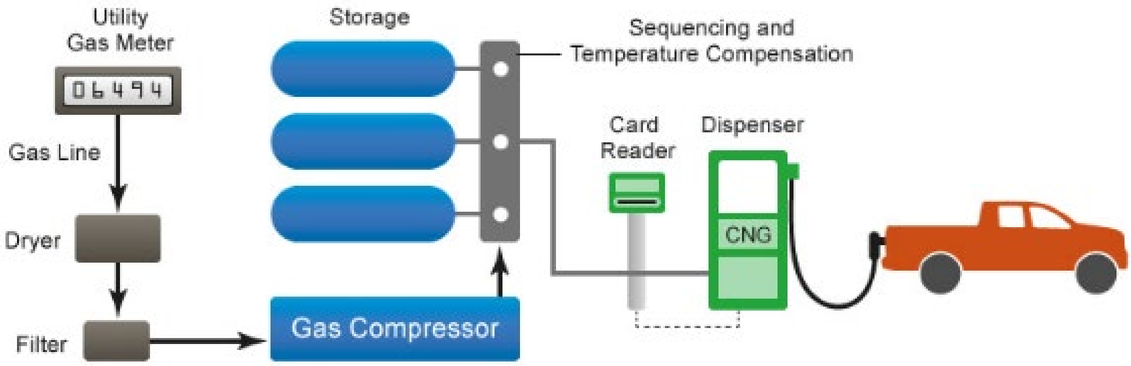

Fig. 3.6. The principle of operation and the main nodes of the CNG fast-acting filling station

Time-filling station (Fig. 3.7.): Time-filling stations are used primarily by fleets and work best for vehicles with large tanks that refuel at a central location every night. At a time-fill station, a fuel line from a utility delivers natural gas at a low pressure to a compressor on site. Unlike fast-fill stations, vehicles at time-fill stations are generally filled directly from the compressor, not from fuel stored in high pressure vessels. The size of the compressor needed depends on the number of vehicles to be fuelled. Although there is a small buffer storage tank, its purpose is not to fill vehicles but to keep the compressor from cycling off and on unnecessarily – wasting electricity and causing undue wear and tear on the compressor. The storage tank is sometimes used to "top off" vehicle tanks during the day. The time it takes to fuel a vehicle depends on the number of vehicles, compressor size, and the amount

[80] https://cryo-tm.com.ua/uk/kontejneri-dlya-zberigannya-ta-transportuvannya-stisnenogo-prirodnogo-gazu/694-kontejnery-dlya-khraneniya-i-transportirovki-szhatogo-prirodnogo-gaza.html
[81] https://afdc.energy.gov/fuels/natural-gas-cng-stations

of buffer storage. Vehicles may take several minutes to many hours to fill. The advantage of using a time-fill station is that the heat of compression is less, and this results in a fuller fill than a fast-fill station can provide. Another advantage is that a fleet manager can control when the vehicles are filled, such as during off-peak hours (like at night) when electricity rates are lower.

Time-fill stations are carefully architected based on the intended use. For example, a transit bus company may need a larger compressor that can deliver 30 to 35 litres per minute. A consumer application may require far less – such as less than 4 litres per hour. These differences account for the large variance in the cost of installation.

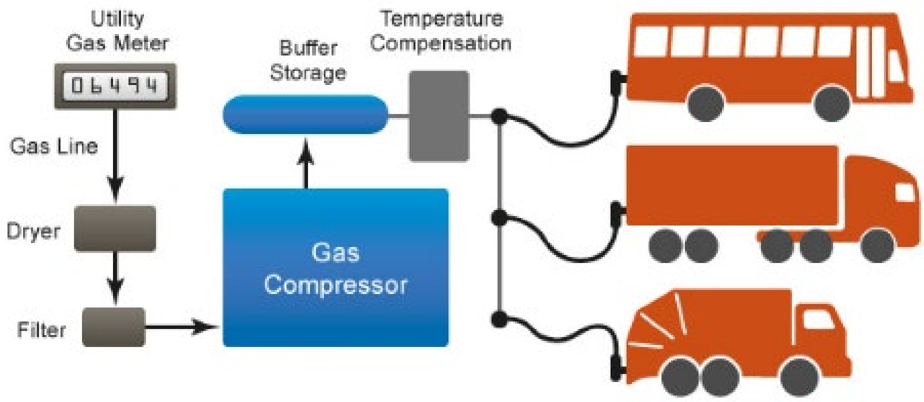

Fig. 3.7. The principle of operation and the main nodes of the CNG time filling station

Combination-filling station (Fig. 3.8): Combination-filling stations include both the fast-fill and time-fill components in one system. The vehicles connected to the time-fill posts are filled directly from the compressor, usually overnight. Vehicles at the fast-fill dispensers are filled from the storage vessels or from the compressor, depending upon need. This design gives a fleet flexibility.

Combination-fill stations typically cost more to build than the previous two station types. A combination-fill station can also be a revenue source if the fast-fill dispensers are made available to the public.

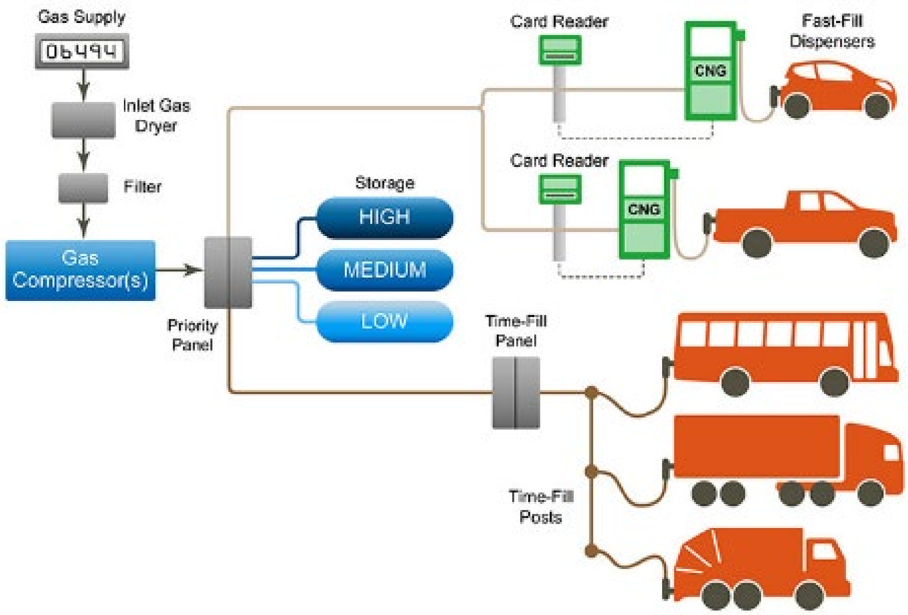

Fig. 3.8. The principle of operation and the main nodes
of the CNG combination-filling station

3.3 Bio-CNG best case studies

Farm-to-Fuel: 650 dairy cows producing biogas[82]

The Birgersson family has been operating the Hagelsrum farm with 650 milking cows since 2008. With initial plans to build a small digester and CHP unit, plans quickly changed when electricity prices dropped in 2011. The family installed DMT's biogas upgrading facility in 2018. Now the family has expanded biogas production and is using the excess bio-CNG to develop their own fuelling stations. Furthermore, some of the bio-CNG is also sold to Eon's existing biogas stations.

DMT's biogas upgrading system enables the family to produce 700.000 KGS of CNG per year. When they couldn't find an outlet for their gas, they decided to create the market themselves. Upscaling production, the Birgersson's developed four fuelling stations in 2019 and 2020.

Cow Power[83]

The "Cow Power" case study explores the production of renewable compressed natural gas (R-CNG)[84] from dairy farm manure through anaerobic digestion and biogas upgrading. This process captures methane emissions, converting them into low-carbon transportation fuel for natural gas vehicles (NGVs).

The project focuses on the Fair Oaks Dairy Farm in Indiana, one of the largest dairy operations in the U.S., which successfully implemented an anaerobic digestion system to process manure from thousands of cows. The biogas is captured, refined into pipeline-quality natural gas, and used to fuel milk delivery trucks and other fleet vehicles. This closed-loop system reduces emissions, lowers fuel costs, and serves as a model for sustainable dairy operations.

The primary feedstock for the anaerobic digesters is manure from approximately 36,000 dairy cows. The facility produces around 775,000 diesel gallon equivalents (DGE) of R-CNG per year. This is sufficient to fuel a fleet of milk delivery trucks, replacing an equivalent amount of diesel fuel and reducing GHG emissions by 40,000 metric tons of CO_2 annually.

Dairy-based R-CNG projects like the Fair Oaks Dairy Farm initiative showcase how farms can turn waste into revenue while reducing emissions and supporting clean energy goals. With supportive policies, corporate investments, and expanding R-CNG markets, "Cow Power" serves as a scalable model for renewable transportation fuel production.

"Waste to Fuel" case study[85]

The "Waste to Fuel" case study explores the production of renewable natural gas (RNG) from organic waste sources, highlighting its technological, economic, and environmental benefits. The study focuses on projects across the U.S. that use anaerobic digestion and landfill gas (LFG) recovery to capture methane emissions and refine them into pipeline-quality RNG. This fuel is then distributed through existing natural gas infrastructure and used in transit fleets, refuse trucks, and heavy-duty vehicles, reducing reliance on fossil fuels and lowering GHG emissions. The feedstock includes landfill waste, wastewater treatment sludge, agricultural waste such as manure and crop residues, and

[82] https://dmt-international.com/project/hagelsrum-farm/
[83] https://afdc.energy.gov/files/u/publication/cow_power_case_study.pdf?da369f0e0b
[84] term used mostly in U.S., equivalent of biomethane
[85] https://afdc.energy.gov/files/u/publication/waste_to_fuel.pdf?4a5d97808e

food waste from industrial and commercial sources. RNG facilities can produce millions of diesel gallon equivalents (DGE) annually, with large-scale LFG projects exceeding 20 million DGE per year, while smaller AD systems produce between 1 to 5 million DGE annually. Key findings highlight RNG as a continuous and scalable renewable energy source that reduces GHG emissions by over 80% compared to diesel. Financial incentives such as Renewable Fuel Standard (RFS) credits, Low Carbon Fuel Standard (LCFS) credits, and state and local renewable energy programs make RNG projects economically competitive. The existing natural gas pipeline network allows for seamless integration into transportation fuelling systems. While high capital costs and regulatory barriers remain challenges, increasing demand for low-carbon fuels and supportive policies create strong growth potential. The study demonstrates that RNG from organic waste is a scalable, economically viable, and environmentally beneficial solution for reducing emissions in the transportation sector. By utilizing waste streams, municipalities, agricultural operations, and private industry can generate renewable fuel, support a circular economy, and contribute to a cleaner energy future.

Gasum's biogas plant at the Munkka waste centre in Lohja, Finland [86].

The facility converts biowaste from the Helsinki region into renewable gas for transport and industry.

Around 60,000 tonnes of biodegradable feedstocks will be processed at the plant into 40 GWh of biogas, equivalent to the annual fuel consumption of 100 heavy-duty vehicles or 4,000 cars a year. The facility will also produce around 50,000 tonnes of organic fertiliser per year for agriculture. The biogas will be injected from the plant directly into the gas network.

The plant has been granted support of €7.83 million by the Ministry of Economic Affairs and Employment under the Bioeconomy and clean solutions key project.

Gasum now has 16 biogas plants in Finland and Sweden, making it one of the largest biogas producers in the Nordics.

EnviTec Biogas and Ohra Energie realise new CNG filling station in Thuringia[87]

A flagship project for the transition to sustainable transport: the order from Ohra Energie GmbH means Lower Saxony-based biogas all-rounder EnviTec Biogas AG will now implement its innovative gas upgrading technology as a single-stage process for the first time. The project encompasses a single-stage gas upgrading plant that is operated with only five SEPURAN® Green Membranes. The purified methane is then fed directly to the CNG filling station. The remaining residual gas stream, consisting of methane and CO_2, known as the 'permeate', is used thermally. This additional heat can be deployed for heating the digester or used in dairy cattle operations. The raw gas is sourced from an existing 400 kW biogas plant run by Agra GmbH Frohndorf/Orlishausen in Sömmerda.

The second step in this joint project plan is an integrated CNG compressor and storage unit, including a dual fuel pump, for a filling station located in the Frohndorf district of Sömmerda. Apart from cooler, fuel pump and card payment point, all of the components are housed in a single container. This is the first time that EnviTec Biogas sources the CNG compressor, cylinder bundle storage, fuel pump and gas upgrading screw compressor from one provider, which also minimises service costs.

[86] https://www.bioenergy-news.com/news/gasums-biogas-plant-in-lohja-finland-now-operational/
[87] https://www.envitec-biogas.com/news/envitec-biogas-and-ohra-energie-realise-new-cng-filling-station-in-thuringia

Stefan Laumann: “Thanks to this CNG filling station, we will soon have filled yet another gap on the map of CNG filling stations in Germany.”

Currently, more than 760 CNG filling stations are usable across Germany, of which roughly 80% (660) offer bio-CNG. In Thuringia, only about 25 CNG filling stations have been completed to date.

3.4 Liquefying of biomethane for bio-LNG production

The liquefaction of biomethane is appropriate when it is necessary to transport it over *longer distances* in the *absence* of the possibility of supplying it to the GTS or GDS, as well as to increase the transport distance at one gas refuelling.

The method of biogas upgrading to biomethane plays a certain role in bio-LNG production, which has also impact on the consumption of electrical energy in the production process. Thus, cryogenic upgrading combines the processes of upgrading and liquefaction, which gives a positive effect on energy consumption (**Fig. 3.9**).

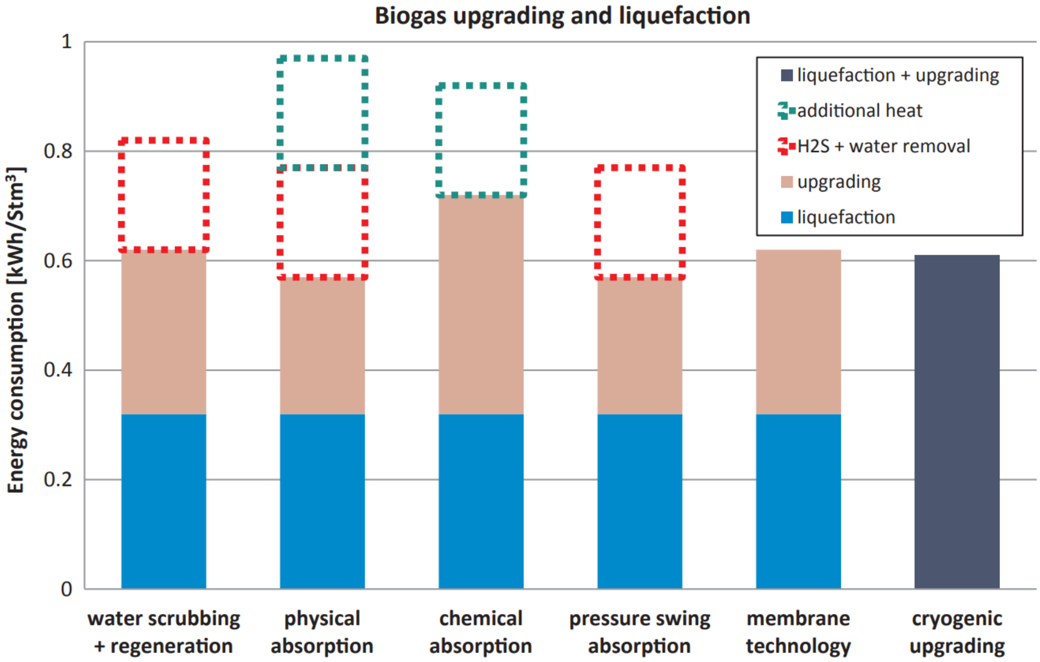

Fig. 3.9. Comparison of energy consumption of different biogas upgrading methods[88].

Biomethane, like natural gas, liquefies at atmospheric pressure at a temperature of minus 162ºC. When the liquefaction pressure increases, the required temperature may be higher. The energy content of bio-LNG is 21,206 MJ/m^3. 1.6 litres of bio-LNG (-162°C, 1.01325 bar) are obtained from 1 m^3 of biomethane (15°C, 1.01325 bar). Liquefaction of biomethane requires from 14 to 20% of the primary energy content of the produced liquid biomethane, depending on the technology used [89].

The equipment characteristics of some of the most common suppliers of natural gas and biomethane liquefaction technologies are shown in **Table 3.2**.

[88] A. Baccioli, M. Antonelli, S. Frigo, U. Desideri, G. Pasini, Small scale bio-LNG plant: Comparison of different biogas upgrading techniques, Applied Energy, Volume 217, 2018, Pages 328-335, ISSN 0306-2619, https://doi.org/10.1016/j.apenergy.2018.02.149

[89] Capra, F., Magli, F., Gatti, M., 2019. Biomethane liquefaction: A systematic comparative analysis of refrigeration technologies. Appl. Therm. Eng. 158, 113815. https://doi.org/10.1016/j.applthermaleng.2019.113815.

Table 3.2. Equipment characteristics of some suppliers of natural gas and biomethane liquefaction technologies.

Technology	Technology Provider	Process and Installation Features	Capacity (tons of biomethane/ day)	Specific Power Consumption (kWh/kg biomethane)
Brayton Cycle	SIAD Macchine Impianti	Nitrogen cycle with a single expander (expansion turbine)	25-60	0.78
	Cryostar/Linde	Nitrogen cycle with a compandor, 3-stage compression with intermediate cooling, and a single expander	20-200	0.6-1.1
	Air Liquide	Nitrogen cycle	4.8-43.2	0.87-0.98
		Nitrogen cycle, installation dimensions: 9.5 × 1.7 × 3 m, weight: 15 tons	4.8	0.93
		Nitrogen cycle, installation dimensions: 11 × 1.7 × 3 m, weight: 17 tons	12	0.78
		Nitrogen cycle with two expanders	13	0.9
	Wärtsilä	Nitrogen cycle with two expanders and simultaneous liquid nitrogen production	30-500	> 0.35
	GE Oil & Gas	Nitrogen cycle	40-6000	0.67
Rankine Cycle	Wärtsilä	Single cycle with mixed refrigerant and water-glycol pre-cooling, installation size: 15 × 15 m including auxiliary areas	30-500 5.5-80	> 0.70
	GE Oil & Gas	Single cycle with mixed refrigerant and pre-cooling	40-6000	0.48
	CryoPur	Combined process for biogas upgrading and liquefaction. Cooling for liquefaction is provided by an integrated refrigeration cascade	0.6-18.5	1.4-1.77
Linde Cycle	Galileo	Pre-cooled cycle, installation size for 15 tons/day: 14 × 3 × 2 m	12-16	0.75-0.84
	Ecospray	Pre-cooled cycle. Installation dimensions: 10 × 2.5 × 2.5 m	4-16	0.7-0.9
Stirling Machine	Stirling Cryogenics	Cryogenic machine based on the Stirling process. Installation size for 2-5 tons/day: 5.9 × 2.35 × 2.2 m	0.15-7	0.43-1.45 (At 2 bar-1.03)
Liquid Nitrogen Cooling	SIAD Macchine Impianti	Micro-liquefaction installation, liquid nitrogen delivery via auto-trailers	2-25	0-0.07

In all cases, the presence of additional components in biomethane to be liquefied should be minimized. Acceptable content is:

- carbon dioxide (CO_2) - no more than 50 ppm (negative effect - it can harden on cold surfaces and cause equipment breakdowns);
- hydrogen sulphide (H_2S) - from 1 to 4 ppm (negative effect - causes corrosion);

- water - from 0.1 to 1 ppm (negative effect - formation of ice on cold surfaces).

If, at the stage of biomethane upgrading, its characteristics have not reached these indicators, its *additional purification* is necessary before liquefaction. For further purification of biomethane before liquefaction, an amine scrubber, adsorption on molecular sieves at variable pressure or temperature are used most often.

Logistic, refuelling stations, and car demand

Transportation of bio-LNG to the filling station is carried out by specialized semi-trailer tankers with the necessary fittings and measuring devices (**Fig. 3.10**). The typical capacity of such tanks is 52 m^3, which allows transporting about 20 tons of bio-LNG. This is the most affordable method for transportation within Ukraine. For transportation to other countries, sea transport can also be considered.

Fig. 3.10. Tanker-semi-trailer for transportation of bio-LNG.

For delivery LNG abroad by sea, standardized containers can also be used. These containers can be delivered directly to the ship. The "Containers of Ukraine" company offers in Ukraine a 20-foot cryogenic tank container T75 for LNG with a volume of up to 26 m^3, priced from UAH 3,105,000 (**Fig. 3.11**).

Fig. 3.11. 20-foot cryogenic tank container T75 for LNG [90]

Liquid biomethane (or liquid natural gas) refuelling systems are relatively simple. Liquid biomethane is stored in special *cryogenic tanks*, the volume of which corresponds to consumption. Such tanks can have two separate pipelines, one of which supplies liquefied biomethane directly to the dispenser, and the other supplies it to the pressure booster pump, from where it flows to the evaporator to obtain

[90] (https://containers.ua/products/tank-konteyner-t50-dlya-szhizhennyih-gazov/

compressed biomethane. Thus, a filling station using liquefied biomethane can serve both bio-CNG and bio-LNG vehicles at the same time. When storing biomethane in liquid form, about 0.12% of its volume evaporates every day[91], and therefore, during long-term storage without consumption, the station must be equipped with a re-condensation unit to preserve gas.

The main safety aspects of using LNG as a fuel are as follows:

- fire and explosion hazard:
  - limits of flammability in air from 5% to 15%;
  - natural gas is odourless and colourless;
- low temperature of liquefied gas / cold streams from compressed natural gas – -163°C:
  - LNG or cold gas can cause serious injury from cooling;
  - ordinary ship steel will be very brittle and may break under LNG exposure.
- the gas tank has a significant energy content:
  - protection from the side and the bottom (collision and grounding);
  - protection against external fire and BLE VE (boiling expanding liquid explosion);
  - protection against mechanical impact.

3.5 Bio-LNG best case studies

Bio-LNG EuroNet project (Shell, Scania, IVECO, DISA, Nordsol) [92]

The Bio-LNG EuroNet project is part of a Global Project for the deployment of a network of 150 LNG refuelling stations across Core TEN-T corridors in Europe by 2026, 5 Bio-LNG production facilities and 20,000 LNG powered trucks to enable the deployment of a large pan-European fleet.

The project aims to improve the European LNG infrastructure, provide LNG trucks, and produce bio-LNG. In total, 39 new LNG fuelling stations will be installed in Poland, Germany, the Netherlands, Belgium, France, and Spain along the Trans-European Transport Network. The route from the Atlantic to the Baltic Sea will be connected with an LNG fuelling site approximately every 400 km. In addition, 2,000 heavy duty LNG trucks are offered by Scania, IVECO and Shell. As part of the project setup, a bio-LNG plant was installed by Nordsol in the Netherlands to produce 3.4 ktons of bio-LNG[93] from biomethane out of waste annually (using a new patented membrane separation technology). This plant delivered the first bio-LNG in July 2021.

Shell is working with industry partners to build necessary infrastructure. This project aims to facilitate the mass adoption of LNG as a road fuel in Europe and supports the EU's goal of a 60% CO_2 emissions reduction by 2050. [94, 95, 96]

Titan to build 'largest' bio-LNG plant at Port of Amsterdam

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[91] Ireblad, T., Dahlgren, S., 2012. Innovative biogas fuelling system alternatives for buses Final Report. Sweco Environ91ment, Baltic Biogas Bus project.
[92] https://trimis.ec.europa.eu/project/biolng-euronet
[93] https://www.europeanbiogas.eu/wp-content/uploads/2021/12/Gas-for-Climate-Market-State-and-Trends-report-2021.pdf p. 34-35
[94] https://trimis.ec.europa.eu/project/biolng-euronet
[95] https://www.europeanbiogas.eu/wp-content/uploads/2021/12/Gas-for-Climate-Market-State-and-Trends-report-2021.pdf p. 34-35
[96] https://www.shell.com/business-customers/shell-commercial-road-transport/sustainability/lng-and-biolng.html

Amsterdam-based Titan LNG[97] has partnered with BioValue[98] to build the world's largest biomethane liquefaction plant in the Port of Amsterdam. The project is set to produce 200,000 tonnes of bio-LNG per year for the marine transport industry.

The plant will provide carbon-neutral fuel for transport ships and trucks supplied mainly by BioValue, with the remaining supplies being sold to refuelling stations and industrial customers.

Titan's bio-LNG fuel will avoid about a million tonnes of CO_2 equivalent emissions per year. Ensuring the project is fully sustainable, biogas for the plant will be sourced from sustainable feedstocks that are compliant with the EU Renewable Energy Directive and are International Sustainability and Carbon Certification (ISCC) certified. The project is due to be ready to produce bioi-LNG by 2025[99].

More than 9 million kilos of bio-LNG will be produced annually[100]

HAM Italy is developing in Faenza, Italy, one of the largest 100% vehicular biomethane plants in Europe, with an estimated annual capacity of 9 million kilos, equivalent to 140 GWh/year.

The project starts from the biogas generated by 2 digesters owned by Caviro Spa, an Italian wine cooperative, where they recover by-products derived from the wine and agri-food chain, which is transformed into biogas. FNX Liquid Natural Gas, a subsidiary of the Ham Group, is in charge of designing and manufacturing the equipment necessary to purify the biogas, up to CO_2 contents below 50 ppm, suitable for liquefying; as well as the liquefaction train that allows obtaining bio-LNG ready for transportation, bound for service stations. It should be noted that the entire installation works with electricity of renewable origin, not producing polluting emissions or greenhouse gases.

In addition, the new 100% vehicular biomethane plant will allow a reduction of more than 600,000 km/year in road traffic of the LNG tanks with which the HAM Italy currently supplies northern Italy, from the port terminals, thus reducing road traffic in general and CO_2 emissions.

HAM Italy, with the development of one of the largest European bio-LNG plants for vehicular use, offers a comprehensive solution to customers who have biogas, taking charge of designing, manufacturing and operating all the necessary equipment that allows optimizing the process: Upgrading, compression bio-CNG, bio-LNG liquefaction, transportation through virtual gas pipeline and sale of biomethane at service stations.

Bio-LNG is a reality in Italy thanks to the SIAD Group working with Vulcangas and Iveco[101]

In November 2020 in the province of Lodi, work on the first agricultural LNG production plant has been completed. The project has brought together companies from an all-Italian supply chain: the SIAD Group, a chemical company specialising in the production and supply of gas; Vulcangas, a company that distributes LPG for both domestic and automotive use; Iveco, a manufacturer of industrial vehicles; and Lucra 96, a farm in the province of Lodi where the innovative plant is located. It is all the result of a year's work, now able to produce up to 3 tons of liquid biomethane per day.

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97 https://titan-cleanfuels.com/
98 https://www.biovalue.eu/
99 https://www.nesfircroft.com/resources/blog/six-new-bio-lng-initiatives-as-the-gas-industry-work-towards-zero-carbon/
100 https://ham.es/en/bio-lng-caviro-italy/
101 https://www.siad.com/news/-/news/822934/Liquefied+Biomethane+is+a+reality+in+Italy+thanks+to+The+SIAD+Group+working+with+Vulcangas+and+Iveco

The supply chain, 100% "made in Italy", is all part of CIB, the Italian Biogas Consortium: each subject, by pooling experience and expertise in its specific sector, has worked in synergy, with the shared objective of creating a project that will give a strong boost to the decarbonisation of transport, promoting the transition from an economy based on the use of fossil fuels to a more sustainable one, all in line with European Green Deal policies.

Biomethane can ensure a high reduction of CO_2 emissions into the atmosphere compared with fossil methane. This first plant is therefore of great strategic value and represents a further endorsement of a virtuous circle: Italy, relying on internal production of biomethane, which is less subject to sudden supply interruptions, will be able to start offering company fleet vehicles an alternative to importing from abroad. A more sustainable solution, also economically.

BioEnergiepark Güstrow plant[102]

The plant has capacity around 9,000 t bio-LNG and 18,000 t of liquid CO2 per year, and CHPs with 3.1 MWel after conversion in 2023. Input materials are 150,000 tonnes p.a., mainly agricultural waste materials. It is Germany's largest integrated bio-LNG plant including CO_2 liquefaction plant.

After a two-year conversion phase, three wide-ranging approval applications and capital investment of more than EUR 50 million, BioEnergie Park Güstrow has entered the trial operation phase. With inauguration of Germany’s largest integrated bio-LNG plant with CO2 liquefaction, EnviTec Biogas AG has achieved a milestone in the production of advanced fuels.

Before being acquired by EnviTec Biogas, the biogas upgrading plant fed into the 25-bar natural gas grid. This required the use of around 400,000 t of substrate as input, which largely consisted of sweet corn, plus whole-crop/grass silage and cereals. The plant’s new operating model involves reducing and reformulating these input materials. As a result, 100,000 t of dry chicken manure from poultry farms is now used, as well as only 40,000 t of renewable raw materials. Following the subsequent upgrading and liquefaction of biomethane into bio-LNG, plus CO_2 liquefaction, the plant handles the entire biogas value chain at a single location. This process alone achieves potential savings of 100,000 t of CO_2.

In the future, the plant will produce 9,600 t of bio-LNG for the heavy goods vehicle sector every year. In terms of mileage, this volume of green HGV fuel could power 50 million truck kilometres a year.

Germany’s largest integrated bio-LNG plant covers the entire value chain on a total area of 17 hectares: Production of biogas, upgrading to biomethane as well as LNG and CO_2 liquefaction. Customers include filling station operators and the food industry.

The biomethane liquefaction system consists of four components: fine purification for the complete removal of moisture and carbon dioxide, liquefaction unit, storage tank and a transfer system for filling transport tanks for delivery to fuelling stations. As a green fuel for trucks, airplanes and ships, bio-LNG makes an important contribution to the transport transition. It is the climate-neutral alternative to fossil LNG.

New biogas plant in Borås[103]

Borås Energi och Miljö will supply the raw gas through its biogas plant, which will then be upgraded and liquefied in St1's new facility. The biogas will be sold on the market as automotive gas. And the

[102] https://www.envitec-biogas.com/references/guestrow
[103] https://www.st1.com/St1-opens-new-biogas-plant-in-Boras

liquefied biogas that can withstand a longer transport will be available for sale throughout the Nordic countries.

In 2024, St1 will open several stations for bio-LNG throughout the Nordic region, now closest in Finland, and the plant, which will have a capacity to produce 60 GWh annually, will enable St1 to meet the increased demand.

The new plant will be part of the pipeline to produce biogas from Boråsarna's food waste and sewage sludge. St1 has also taken over the public filling stations and garbage truck filling point previously owned by Borås Energi och Miljö. Cooperation will ensure close cooperation throughout the production process.

St1 intends to expand its biogas business throughout the Nordic region, expanding not only the production and filling stations for both bio-CNG and bio-LNG, but also through strategic collaborations and acquisitions to strengthen the biogas business in the market.

New Bio-LNG fueling station in Schwedt/Oder, Germany[104]

On February 27, 2025, Verbio SE announced the opening of a new bio-LNG fuelling station at Passower Chaussee 111 in Schwedt/Oder, Germany. This station, operational since early February, offers transport companies 24/7 access to environmentally friendly and cost-effective bio-LNG, presenting a viable alternative to diesel that reduces both costs and carbon footprints.

Since 2021, Verbio has been expanding its network of bio-CNG and bio-LNG stations across Germany, with 19 company-owned stations currently in operation and more planned in the coming months. Additionally, a partnership with BayWa Power Liquids GmbH allows carriers to access Verbio's bio-LNG at eleven BayWa LNG stations.

Biomethane, available as compressed (bio-CNG) or liquefied (bio-LNG) natural gas, powers standard trucks with ranges between 500 to 750 kilometres per tank for bio-CNG and 1,000-1,600 kilometres for bio-LNG. Manufacturers like Scania, IVECO, Volvo, and Mercedes-Benz offer compatible vehicles. Verbio is also transitioning its fleet, with 120 out of nearly 150 trucks already converted to CNG or LNG, primarily using its own bio-CNG and bio-LNG.

3.6 Technical aspects and economy issue of bio-CNG and bio-LNG production

The production of bio-CNG and bio-LNG based on biomethane includes a complex of technological and logistical solutions, which, in turn, can differ significantly from each other, depending on the types of raw materials used and product concepts of the project.

Fig. 3.12 shows the main components of the cost of bio-CNG and bio-LNG. It should be noted that depending on the type and cost of raw materials, the scale of the project and the technologies used, the cost of biomethane production in Ukraine can range from 300 to 1000 Euro/nm^3 and higher (**Fig. 3.13**).

[104] https://www.verbio.de/en/products/verbiogas/

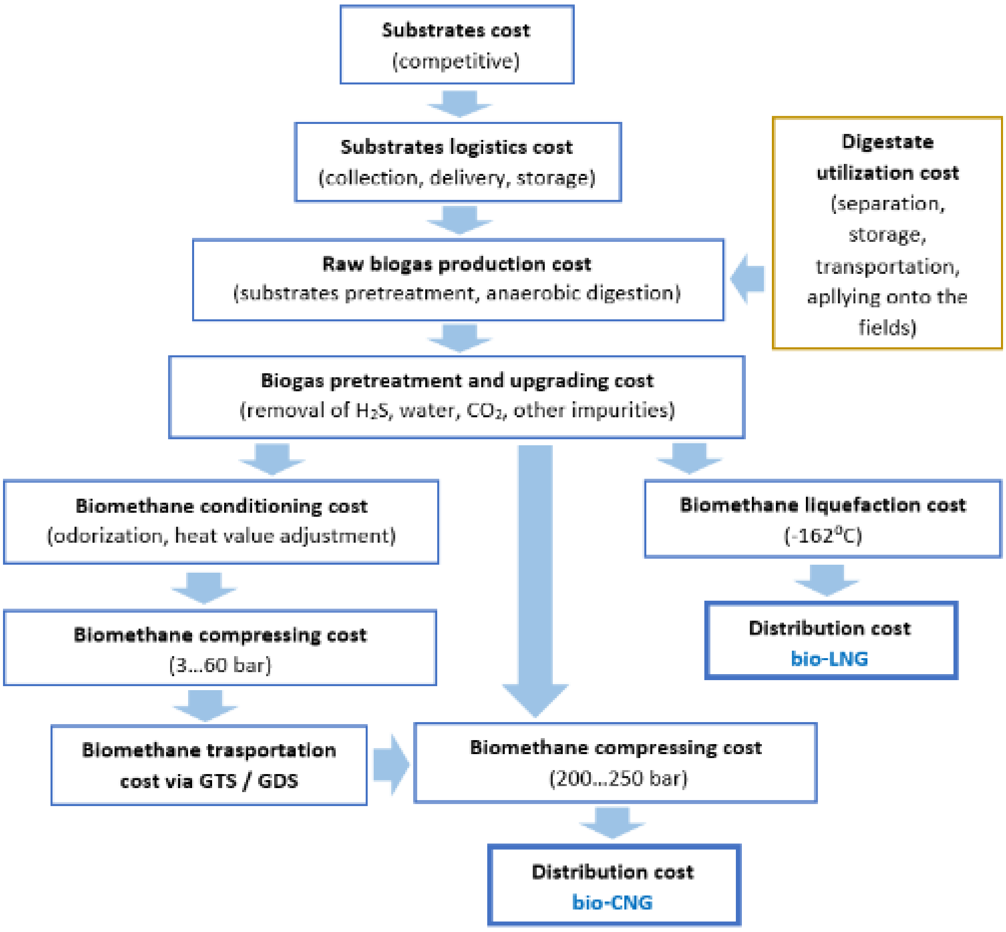

Fig. 3.12. The main components of the production cost of bio-CNG and bio-LNG from biomethane.

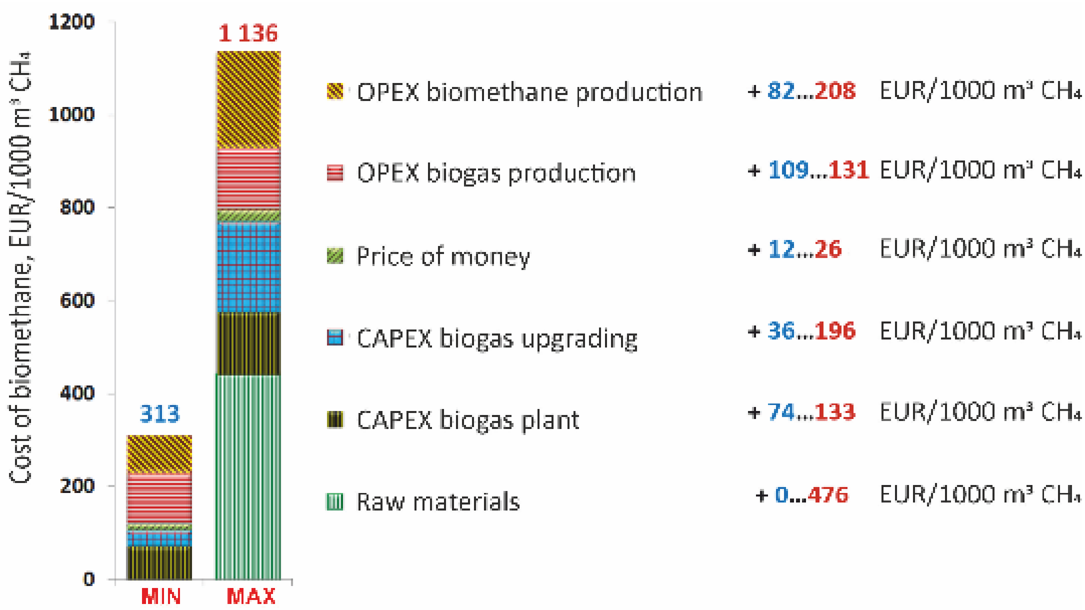

Fig. 3.13. Full cost structure of biomethane in Ukraine[105]

[105] Expert assessment of UABIO

Cost of biomethane transportation via GTS / GDS

If it is necessary to transport biomethane through the gas transportation system of Ukraine, transportation costs will arise. Tariffs for the natural gas transportation of the GTS are determined by the GTS Operator. Thus, as of 2022, tariffs for NG transportation to EU countries across the border of Ukraine are set at EUR 15.04-16.24 per 1,000 m^3 per day, excluding VAT, depending on the exit point[106]. Increasing and decreasing coefficients are also set for transportation services.

Thus, the fee is actually charged for the input capacity of the connected gas production enterprise, and not for the volume of gas transportation.

The GTS operator also set tariffs for gas transportation within Ukraine. Thus, at the entrance to the GTS, the gas production enterprise will need to pay UAH 464.37 (EUR 10.7) per 1,000 m^3/day, and at gas exit points - UAH 501.97 (EUR 11.5) per 1,000 m^3/day (without VAT).

Costs of Bio-CNG mother and daughter stations

In the case of CNG delivery to gas stations by trucks in cylinders, the so-called mother and daughter stations are used, the first for compressing natural gas or biomethane and pumping it into cylinders, the second for receiving these cylinders and refuelling CNG transport.

Fig. 3.14 shows an approximation of the cost of mother stations that compresses gas before pumping it into auto cylinders for further transportation, based on available data[107,108,109].

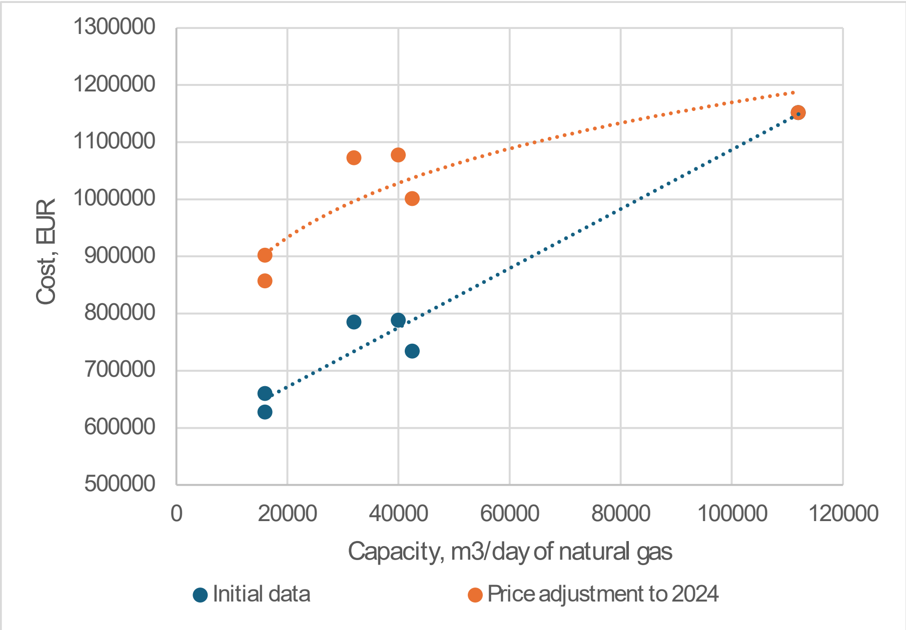

Fig. 3.14. Cost of CNG mother stations

[106] https://tsoua.com/kliyentam/taryfy-na-transportuvannya-gazu/
[107] https://www.semanticscholar.org/paper/System-analysis-of-mobile-CNG-transport-as-a-way-to-Sattari-Roshandel/cdaedd32d09b79d57e031f4b49359f64aa919eda
[108] https://nairametrics.com/2023/08/31/expert-interview-what-it-cost-to-build-a-cng-mother-station/
[109] https://journal.lemigas.esdm.go.id/index.php/LPMGB/article/view/678/456

Here and further in the graphs we will provide both the initial data, representing data from open sources for different years, and their conditional reduction to 2024 prices, based on the Chemical Engineering Plant Cost Index (CEPCI)[110].

For example, mother station capable of supplying up to sixteen (16) CNG trucks, each with an average skid capacity of 7,000 standard cubic meters (equivalent to 6,750 litres) per truck, comes at an estimated cost of approximately $1.2 million (1.15 million EUR) on average[111].

The approximation of the cost of daughter stations is shown in **Fig. 3.15.**

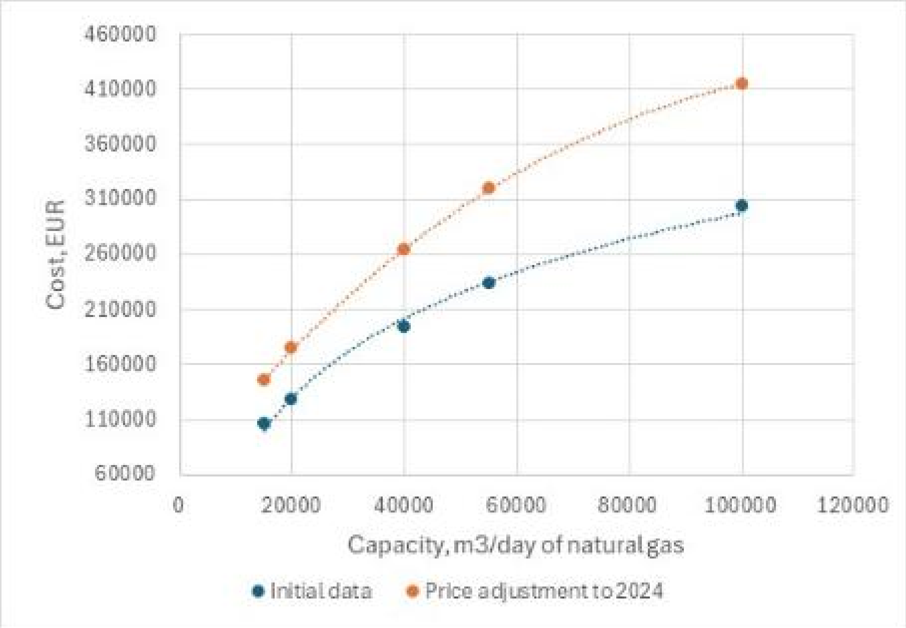

Fig. 3.15. Cost of CNG daughter stations[107]

Costs of Bio-CNG trailers

To deliver CNG from the mother station to the daughter station, special cylinder systems are used, transported by auto trailers, as shown in **Fig. 3.5**. Trailers comprise of a skeletal framework upon which a container holding high-spec gas cylinders is installed. For high-volume transportation, 'Type 4' cylinders are used, which are filament-wound composite cylinders wrapped around a plastic former. The composite is generally either glass or carbon fibre. The skeletal trailer is just the bottom of the trailer, base chassis and wheels.

Fig. 3.16 shows an approximation of the cost of CNG trailers (without trucks), based on available data[112],[113].

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[110] https://toweringskills.com/financial-analysis/cost-indices/

[111] https://lpginnigeria.com/details/the-cost-of-building-cng-mother-stations-and-the-road-ahead-for-sustainable-energy

[112] https://www.energynetworks.org/assets/images/Resource%20library/GGG%20Biomethane%20Injection%20Study%20-%20Phase%201%20report.pdf

[113] https://questcanada.org/wp-content/uploads/2018/08/2012_Feasibility-Study-Compressed-Natural-Gas-in-NS-Phase-1.pdf

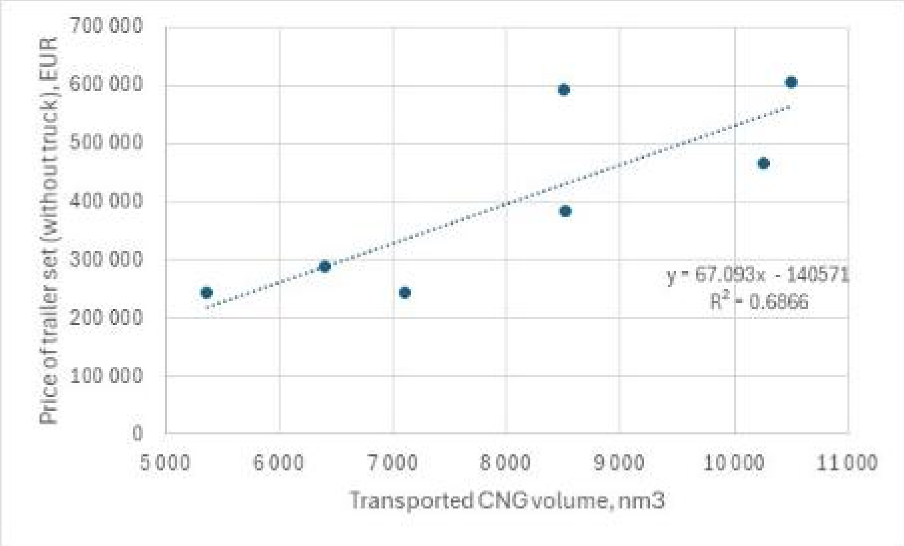

Fig. 3.16. Approximation of the cost of CNG trailers

Biomethane compressing

The need to compress biomethane may arise when it is necessary to supply biomethane to the GDS or GTS, where the pressure is higher than the pressure at the outlet of the biogas upgrading plant. Such a need will arise in any case when feeding into GTS, where the pressure is 50-75 bar. When feeding into the gas distribution networks with a pressure of 3-6 bar, the need to pressurize biomethane after upgrading is minimal or completely absent, since the exit pressure of biomethane may reach 10-14 bar. But this need is high enough if biomethane is compressed to the pressures used in CNG storage and transportation systems, as well as for the cars refuelling.

Fig. 3.17 shows the estimated specific electrical energy consumption for compressing biomethane to final pressures in the range of 6-350 bar (this is approximately 0.6-35 MPa), for three values of the initial biomethane pressure -1 bar, 5 bar and 10 bar.

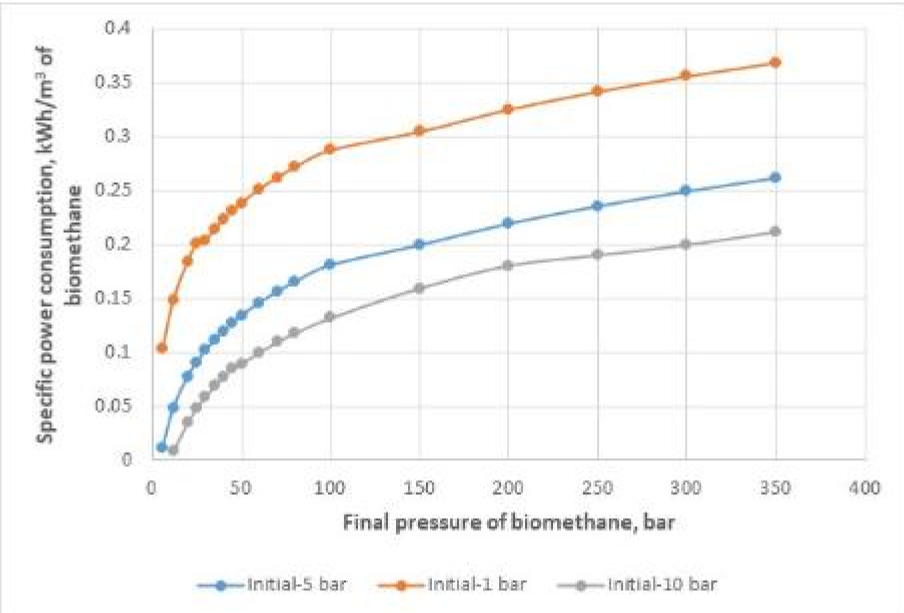

Fig. 3.17. Dependence of the specific consumption of electricity on the initial and final pressure of biomethane.

Costs of Bio-CNG fuelling stations

Table 3.3 below provides estimated cost ranges for CNG stations of various daily fuel demands based on the available data[114]. These estimates include the costs of engineering, equipment, and installation at a site with the specified assumptions. The estimates do not include costs associated with unusually complicated installations, difficult permitting issues, compressor redundancy, or similar factors that could increase the total project cost.

Unless otherwise noted, the estimates for fast-fill stations assume a vehicle fuelling window in which 70% of the fuel is dispensed during two hours in the morning and two hours in the afternoon. For time-fill stations, the compressor is assumed to run for 10 hours per day. Fast-fill cost estimates for the small, medium, and large stations include a priority panel and credit card reader. All scenarios include a gas dryer.

Table 3.3. Average costs of CNG-fuelling stations

Filling capacity, m^3 of natural gas per day*		Cost range, thousand EUR	
Time-filling			
18	36	8.6	9.6
72	143	33.6	48
359	717	240	480
1793	2870	528	816
Fast-filling			
72	143	43.2	72
359	717	384	576
1793	2870	672	864
5380	7174	1152	1728
*- natural gas in standard conditions			

Other source[115] gives some idea of the prices of larger-scale CNG filling stations (**Fig. 3.18**). In **Fig. 3.18**, DGEs means the diesel gallon equivalent, 1 DGE equals to 1.136 of gasoline gallon equivalent (GGE)[116] or about 4 m^3 of natural gas in the standard conditions. It should be noted that the upper end of the station throughput range (300 thousand DGE) is uncommon.

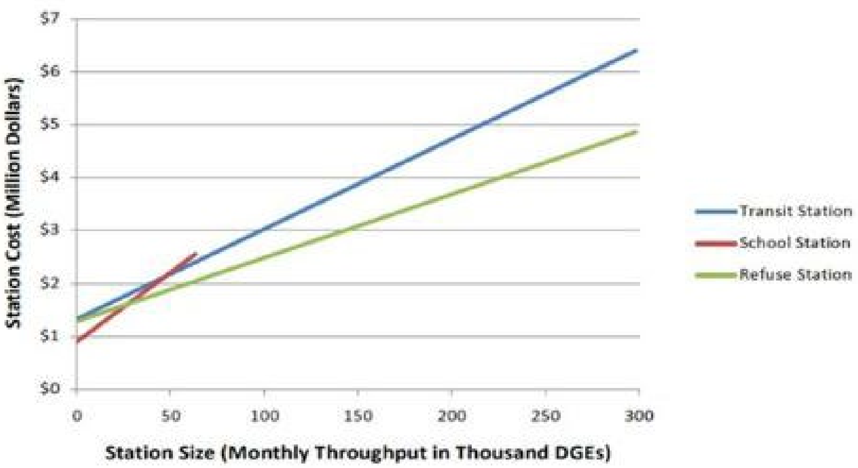

Fig. 3.18. The relationship between the size of a CNG fuelling station and its cost.

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[114] https://www.nrel.gov/docs/fy14osti/62421.pdf
[115] Natural Gas-powered Cars and Trucks (2015). Editor: Hayley Ackerman. ISBN: 978-1-63463-971-2. Nova Science Publishers, Inc.
[116] https://energy.ozinga.com/2020/10/12/gge-and-dge-measuring-cng/

Comparison of transport fuel consumption when using diesel, gasoline and CNG

A comparison of the specific consumption of LNG compared to diesel fuel indicates a higher consumption of LNG in kg/100 km for different types of transport (**Table 3.4**).

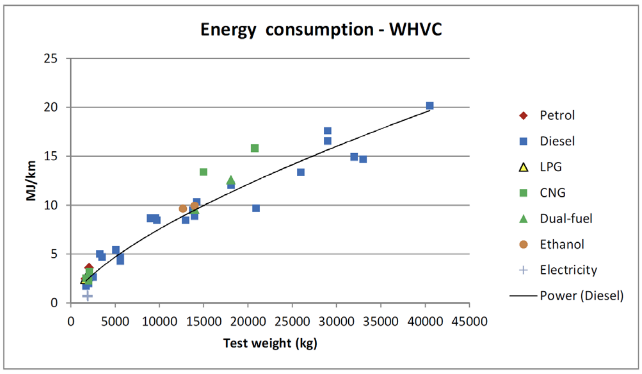
Table 3.4. Diesel vs CNG consumption comparison[117]

Category	Diesel Vehicle	CNG Vehicle	Average Gross Weight (kg)	Consumption of Diesel (kg/100 km)	Consumption of CNG (kg/100 km)
Passenger Cars	Volkswagen Golf 1.6 D BlueMotion Technology	Volkswagen Golf TGI 1.4 BlueMotion	1400	4.2	3.5
Light Commercial Vehicles	Fiat Fiorino 1.3 Multijet 75 HP	Fiat Fiorino 1.4 Natural Power	1700	3.8	4.4
Buses	Diesel Bus	CNG Bus	12,000	19.0	21.0
Heavy-Duty Trucks	Diesel Truck	CNG Truck	18,000	16.6	22.2

Fig. 3.19 presents the assessments and literature review of the relative change in energy consumption and CO_2 emissions of spark ignition NG engines compared to diesel engines for heavy-duty applications of Daimler and MAN.

Energy consumption relative to diesel engines	CO_2 emissions relative to diesel engines	Source
21.5 %	N.A.	Langshaw et al. (2020)
19.0 %	-7.1 %	Cenex (2019)
24.1 %	N.A.	DLR; TUHH (2019)
N.A.	-10.1 %	TNO (2018)
N.A.	-8.9 %	TNO (2017)
16.8 %	-12.0 %	NGVA Europe (2017)
24.3 %	-3.2 %	LBST (2016)
11.1 %	N.A.	Burnham et al. (2016)
21.0 %	-0.5 %	IFEU (2015)
23.1 %	-7.4 %	IFEU (2015)
26.1 %	-3.6 %	dena (2014)
31.8 %	8.7 %	cenex (2012)

a) Data according to Oeko-Institut e.V. and ICCT[118]



b) Data according to IEA Alternative Motor Fuels Technology Collaboration Programme[119]

Fig. 3.19. Review of the relative change in energy consumption and CO_2 emissions of spark ignition NG engines compared to diesel engines for heavy-duty applications

[117] https://iea.blob.core.windows.net/assets/imports/events/252/Nylund_Vehicle_energy_efficiencies.pdf
https://cngeurope.com/natural-gas-vehicles/volkswagen/
https://carbonn.org/uploads/tx_carbonndata/Gas%20Vehicle%20guide_dec_2010%5B1%5D.pdf
https://www.researchgate.net/figure/The-fuel-costs-for-different-bus-technologies-per-100-km-1-diesel-bus-2-CNG-bus_fig1_303596909
https://hal.science/hal-03084846/document
[118] https://theicct.org/wp-content/uploads/2021/06/LNG-in-trucks_May2020.pdf
[119] https://www.iea-amf.org/app/webroot/files/file/Annex%20Reports/AMF_Annex_49.pdf

In average, spark ignition NG engines consume 22 % more energy (i.e., are 18 % less efficient) than diesel heavy-duty engines. However, they emit, in average, 4.9 % less CO_2 emissions than their diesel counterparts, thanks to the lower carbon content of the fuel.

Costs of LNG fuelling stations

Costs of LNG fuelling stations are estimated based on the available sources, in dependence of LNG storage capacity[120] (**Fig. 3.20**). A large fleet LNG station with dispensing capacity of 40,000 to 200,000 m^3/day ranges from $2.25 to $7.5 million.

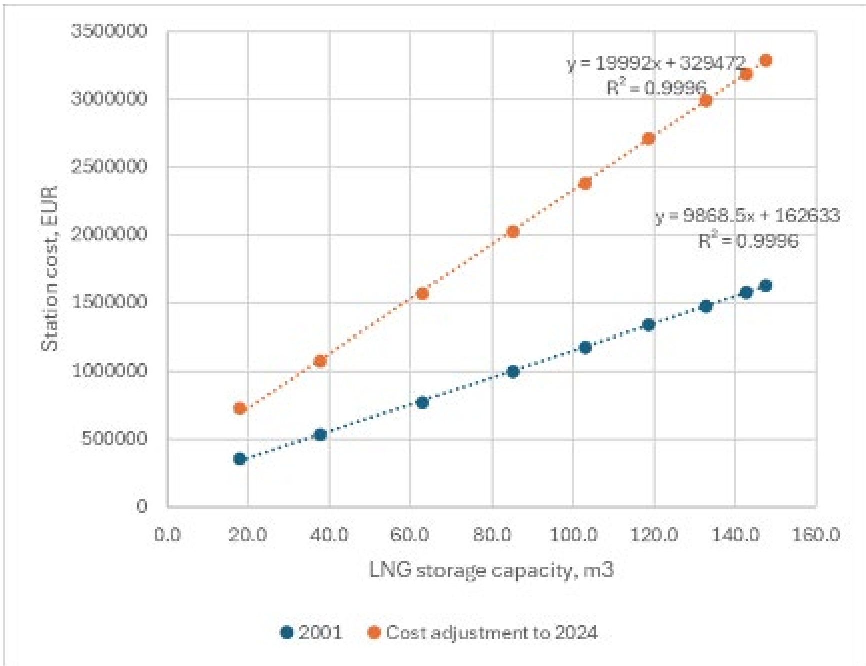


Fig. 3.20. Cost approximation of LNG refuelling stations.

Costs of LNG production plants

Based on our experience, the cost of biomethane liquefaction plants may be approximated as following (**Fig. 3.21**). These costs include polishing station and liquefaction plant and do not include auxiliary equipment like LNG storing tank and fuelling column for LNG-loading trucks, as well as installation and commissioning. The specific electricity consumption for liquefaction process is presented on **Fig. 3.22**.

[120] https://www.ourenergypolicy.org/wp-content/uploads/2012/05/11_1803_anga_module5_lng_dd9.pdf

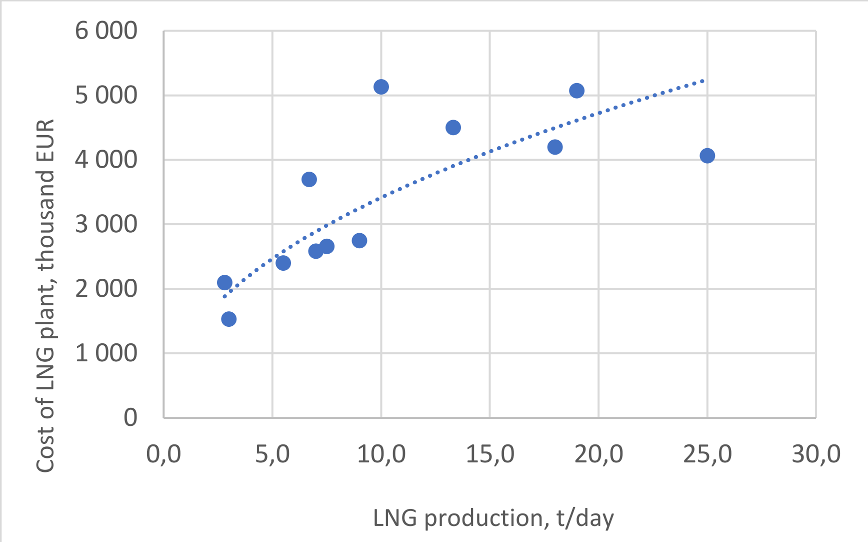


Fig. 3.21. Cost approximation of LNG production plants.

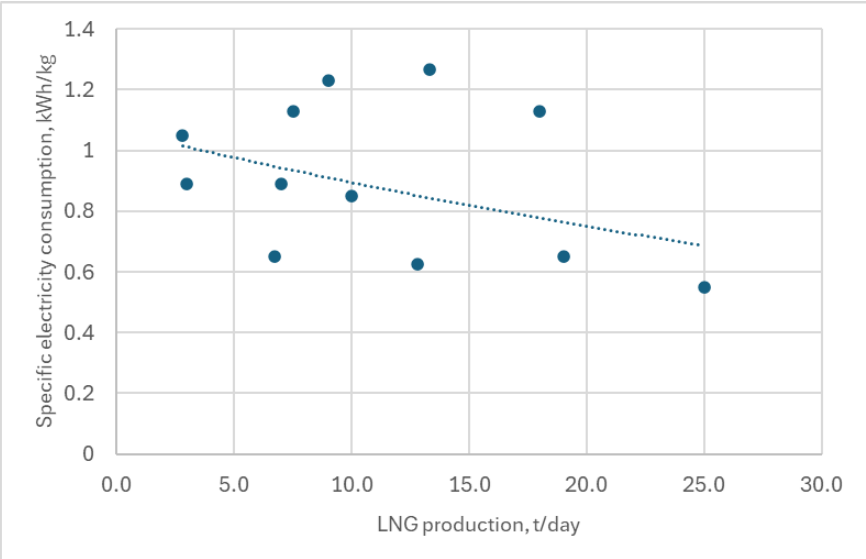


Fig. 3.22. Approximation of specific electricity consumption for different LNG production capacities.

3.7 Comparison of different options for production of transport fuel based on biomethane

Let's determine what economic results can be if we consider a biomethane plant that produces 6 million m^3 of biomethane per year, while the business owners decide not to feed it into natural gas pipelines, but to produce transportation fuels. We will determine the capital and operating costs for the production of transportation fuel, as well as the selling price of the fuel necessary for the capital costs to pay off in 5 years (without discounting) and compare this price with the current price of diesel fuel.

The following options are considered:

Option 1 - CNG production. Biomethane is compressed to 30 MPa at the biomethane plant production site (the so-called mother station) and pumped into gas cylinders for transportation over a distance of 75 km to a daughter station from which CNG vehicles are directly refuelled.

Option 2 - CNG production when it is possible to organize an CNG refuelling station relatively close to the biomethane plant (5 km). Then it is planned to lay a biomethane pipeline from the biomethane plant to the location of the refuelling station. In this case, the refuelling station performs the functions of CNG production, storage and refuelling of vehicles.

Option 3 - LNG production. LNG is produced at the biomethane plant production site, then loaded into a tanker for transportation to a filling station 75 km away, where it is pumped into the filling station tanks. The filling station performs the functions of storing LNG and refuelling vehicles.

Option 4 - CNG production from natural gas. We consider this option with conditions similar to Option 2, but the raw material will be natural gas. We introduce this option for comparison, as one that has examples of implementation in Ukraine. Comparing other options with this option will allow us to draw conclusions about what features biomethane production imposes on the production of transport fuel.

The main assumptions made for the calculation are shown in **Table 3.5** and **Table 3.6.**

Table 3.5. Main assumptions for the abovementioned options 1-4.

Parameter	Value
Exchange rate UAH/EUR	43.4737
Electricity price (retail market, 2-nd voltage class consumer), without VAT	8.85
Average monthly salary with accruals, EUR	842
Price of natural gas, EUR/1000 m^3, without VAT	460.0
Retail price of diesel, EUR/kg, incl. VAT	1.265
Specific GHG emission for diesel, kg CO_2-eq./kg diesel	3.19
Annual biomethane production, m^3	6,000,000
Daily biomethane production, m^3	16,438
Daily bio-LNG production, ton	11.7
Operating cost of biomethane, EUR/1000 m^3	500
CAPEX of biomethane plant, EUR	10,200,000
Distance of gas delivery by pipeline, m	5000
Distance of CNG/LNG delivery by truck, km	75
Income tax, %	18
Average degree of excess energy consumption of CNG compared to diesel fuel by vehicles, %	23.5
Planned simple payback period for biomethane plant operator, years	5
The same, for operator of CNG made from natural gas, years	3

Table 3.6. Assumptions of specific CO_2 emissions.

Specific CO_2 emissions, g/kg fuel	Fuel	NCV, MJ/kg	CO_2 emissions, g/GJ	CO_2 emissions, kg/ kg fuel
	gasoline	44.3	69,300	3.07
	diesel	43	74,100	3.19
	natural gas	48	56,100	2.69

We will base the determination of capital and operating costs on the dependencies described above, taking into account the scale of biomethane production, which, in turn, determines the required scale of filling stations, assuming that all produced biomethane is converted into transport fuels.

Based on the data in **Fig. 3.13** above, we estimate the operating costs for biomethane production at an average level of **500 Euro/1000 m^3**. We further sum this value with the operating costs of producing transport fuel from biomethane.

The results obtained are shown in **Table 3.7**. Based on these calculations, a number of conclusions can be drawn:

1. The production of transport fuel on a scale of 6 million m^3 of biomethane per year requires additional capital expenditures of €1.4-6.7 million. The most expensive option in terms of capital expenditures is LNG production.
2. If we compare the price of biomethane equivalent of 1 kg of diesel fuel for different biomethane fuels, we see that almost all options are more expensive than diesel fuel, except of CNG produced from natural gas (**Fig. 3.23**).
3. To ensure a simple payback period of 5 years, a large surcharge is required to the cost of biomethane-based fuel. In this sense, CNG produced from natural gas looks better, as it is not linked to the capital costs of biomethane production, so the selling price can be significantly lower (**Fig. 3.24**, **Table 3.7**).
4. If we consider the possibility of increasing the CO_2 tax for fossil fuels and levelling the prices of diesel fuel and fuels produced from biomethane due to this, the tax level should be 138-348 EUR/t CO_2, which significantly exceeds the current level of prices for GHG emissions in the EU ETS system.

Table 3.7. Results of cost estimation for the Options 1-4 for production of transport fuel based on biomethane

Indicators	Options							
	Biomethane						Natural gas	
	Option 1 (CNG, two stations)	**Comments**	**Option 2 (CNG, pipeline+ one station)**	**Comments**	**Option 3 (LNG, liquefaction+ one station)**	**Comments**	**Option 4 (CNG, pipeline+ one station)**	**Comments**
Capital expenditures, EUR:	**2 545 875**	TOTAL, including:	**1 422 456**	TOTAL, including:	**6 761 268**	TOTAL, including:	**1 329 119**	TOTAL, including:
	907 810	CNG mother station	266 574	Biomethane pipeline	4 949 329	LNG plant	266 574	NG pipeline
	1 483 329	CNG trucks (3 vehicles)	93 336	Compressor station	282 947	LNG trucks (1 vehicle)	0	Compressor station
	154 736	CNG daughter station	1 062 546	CNG compressing and refuelling station	1 528 992	LNG refuelling station	1 062 546	CNG compressing and refuelling station
Annual operating expenditures, EUR:	**619 617**	TOTAL, including:	**464 494**	TOTAL, including:	**1 653 617**	TOTAL, including:	**441 079**	TOTAL, including:
	340 535	Electricity	349 083	Electricity	1 324 033	Electricity	322 708	Electricity
	92 441	Operating and Maintenance	89 481	Operating and Maintenance	220 280	Operating and Maintenance	92 441	Operating and Maintenance
	27 782	Salary	25 930	Salary	27 448	Salary	25 930	Salary
	158 858	Transportation	0	Transportation	81 856	Transportation	0	Transportation
Cost of production and distribution, EUR/1000 m3	103		79		276		74	
Total operating cost, EUR/1000 m3	603		579		776		534	
Required price of biomethane, EUR/1000 m3 incl. VAT	1225		1146		1596		642	

Indicators	Options							
	Biomethane						Natural gas	
	Option 1 (CNG, two stations)	**Comments**	**Option 2 (CNG, pipeline+ one station)**	**Comments**	**Option 3 (LNG, liquefaction+ one station)**	**Comments**	**Option 4 (CNG, pipeline+ one station)**	**Comments**
Required price of biomethane*, EUR/kg incl. VAT	1.65		1.54		2.15		0.86	
Price of biomethane equivalent to 1 kg of diesel fuel, EUR incl. VAT	1.82		1.70		2.37		0.95	
Total CAPEX incl. biomethane plant, EUR	**12 745 875**		**11 622 456**		**16 961 268**		**1 329 119**	
Income, Euro/year	7 349 270		6 873 124		9 577 143		3 849 326	
Expenses, Euro/year	3 619 617		3 473 380		4 653 617		3 201 369	
Earnings before taxes, Euro/year	3 729 653		3 399 744		4 923 526		647 957	
VAT, %	621 609		566 624		820 588		107 993	
Profit tax, Euro/year	559 448		509 962		738 529		97 194	
Net profit, Euro/year	2 548 596		2 323 159		3 364 410		442 771	
Simple payback period, years	5.0		5.0		5.0		3.0	
Required CO2 tax, EUR/t	175		138		348		–	
*- Required price of biomethane means the price, required to recover all capital costs in 5 years (3 years for CNG from natural gas)								

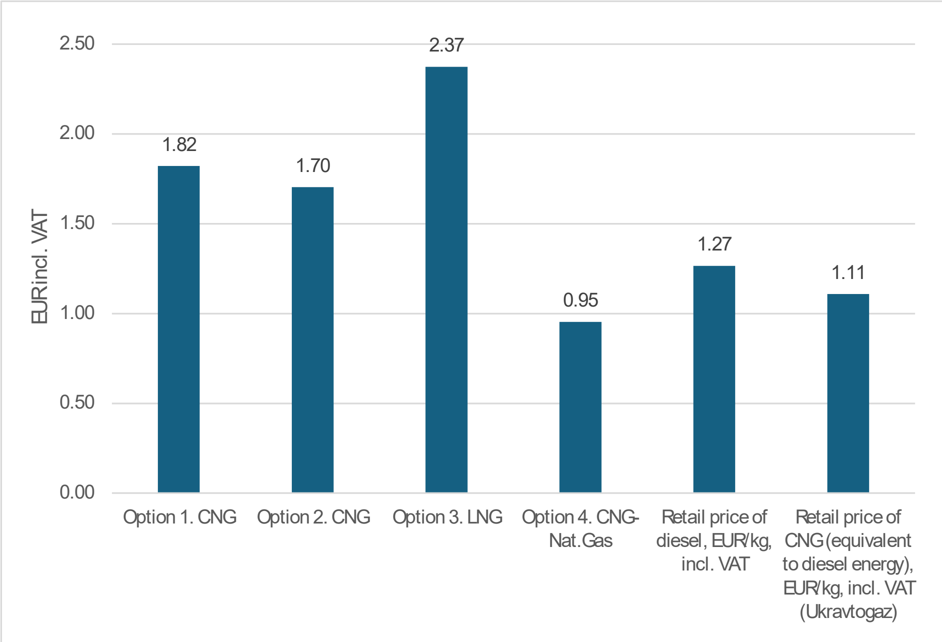


Fig. 3.23. Price comparison of biomethane equivalent to 1 kg of diesel fuel, EUR incl. VAT.

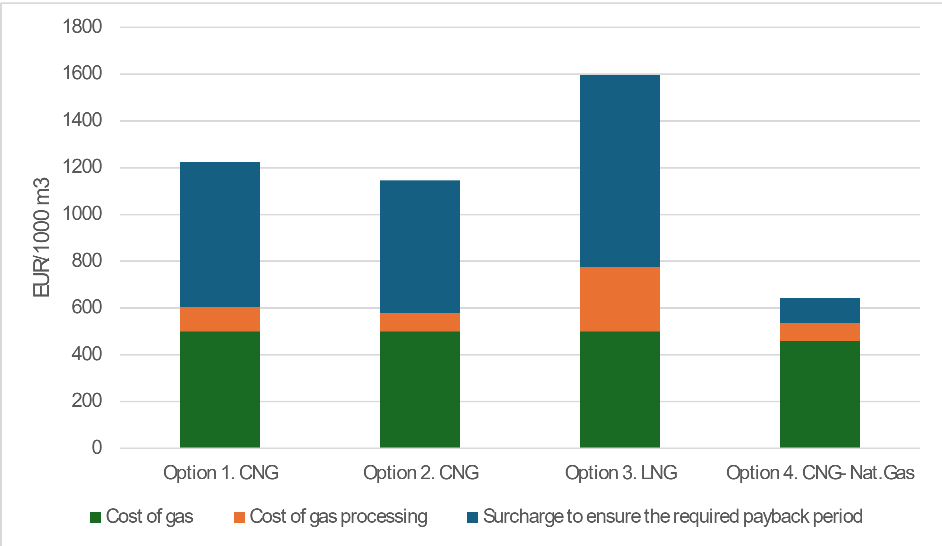


Fig. 3.24. Cost structure of the gas price, EUR incl. VAT.

Competition with electric vehicles

In terms of energy costs, the specific costs of both liquid and gaseous fuels for vehicles are more than twice those for electric vehicles (**Fig. 3.25)**.

Given the current price ratios for fuel and electricity, electric vehicles are profitable for the population, but for businesses there is almost no difference (**Table 3.8**).

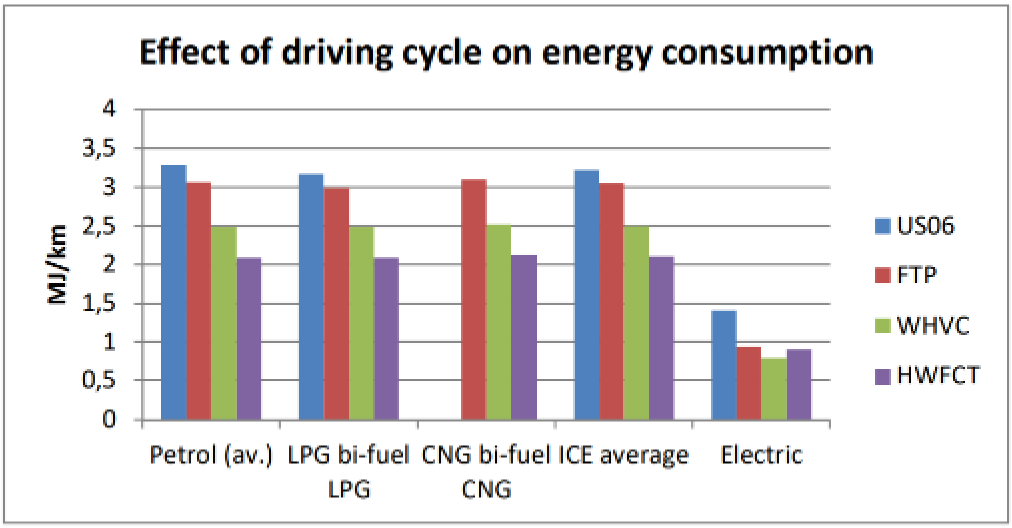


Fig. 3.25. The effects of test cycle on energy consumption (light-duty commercial vehicles, gross weight 2,500 – 5,000 kg)

Table 3.8. Comparison of CNG and electricity costs for the same transportation distance

CNG	LHV, MJ/kg	48	
	Price	UAH/nm^3 incl. VAT	UAH/MJ incl. VAT
		32.4	0.9375
Electricity	Price for Population	UAH/kWh	UAH/MJ
		4.32	1.2
	Price for Business, incl. VAT	9.0	2.5
Energy consumption ratio "fuel-to-electricity"		2.5	
Fuel costs change (comparing to CNG) for:		population	business
		-49%	7%

The conclusion regarding the benefit to the population applies only to the case of using "home" charging at the appropriate tariff. If charging is done at specialized "fast" charging stations, the benefit to electric transport is questionable.

Electric charging stations in Ukraine offer the following charging options[121]:

- Charging with CCS cable – 120 kW/150 kW at a price of 16.99 UAH/kWh.
- Charging with GB/T DC cable – 60 kW at a price of 15.99 UAH/kWh.
- Type 2 – 22 kW, with cable. Price: 12.99 UAH/kWh

[121] https://electro-mobility.com.ua/blog/skilky-koshtuie-zariadyty-elektrokar-u-chervni-2024-roku/

4. Road transport in Ukraine

4.1 Fuel consumption statistics

Fossil fuels

It should be noted that after the introduction of martial law in Ukraine in February 2022, the State Statistics service of Ukraine (SSSU) considerably restricted the publication of statistical data. In particular, that applies to the consumption of fuels and energy carriers. That is why the latest available **official** statistical data are for 2021.

In Ukraine, petrol (gasoline) and diesel fuel are key energy carriers for road transport, agricultural machinery, construction machinery and industrial equipment. Diesel fuel is used mainly in freight transport, the agricultural sector and special equipment, while gasoline remains the main type of fuel for passenger cars. In recent years, there has been a tendency to increase the share of diesel fuel in the overall consumption balance due to its economy and higher torque of internal combustion engines.

The consumption of petrol and diesel in Ukraine has fluctuated during the last decades. During the period of 2000-2021, the highest values were 6.3 Mt/y for diesel in 2012 and 5.1 Mt/y for petrol in 2008 (Fig. 4.1). After 2008, the consumption of petrol was constantly reducing (except for 2020-2021), while the consumption of diesel was just fluctuating around ~5.5 Mt/y. The use of liquefied propane and butane was much lower, though the general trend was towards increase: 1.3 Mt/y in 2021 versus 0.31 Mt/y in 2007. From 2006, the statistical data include the volume of retail sales through the filling stations.

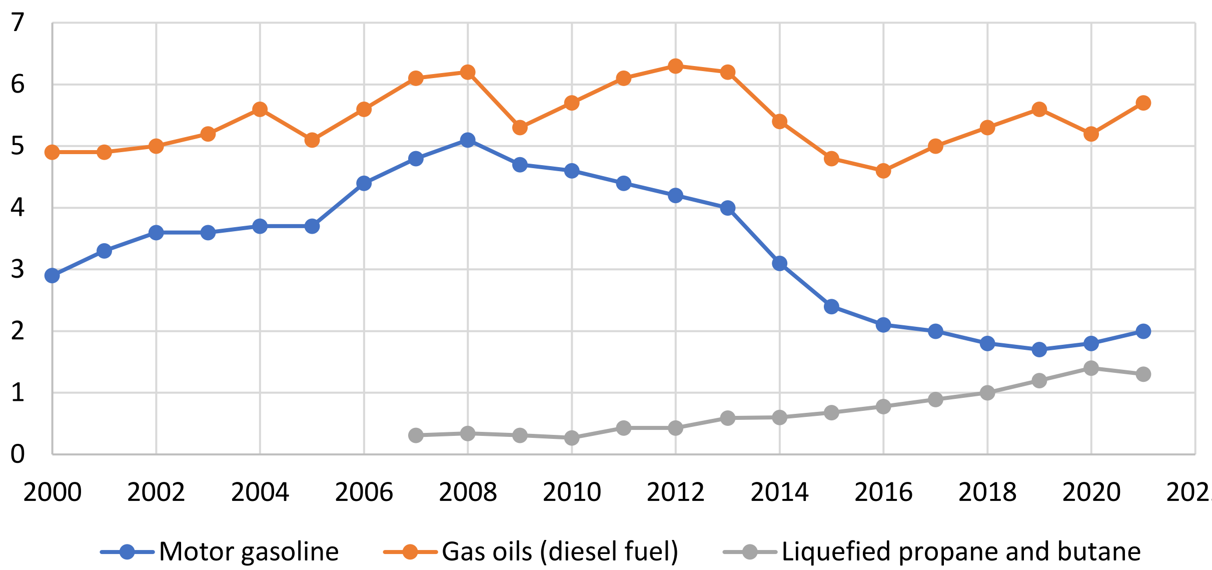


Fig. 4.1. Dynamics of consumption of motor fuels in Ukraine, Mt[122]

More detailed statistical information on the consumption of motor fuels in Ukraine in 2017-2021 is presented in Table 4.1. The use of liquid motor fuels during this period was quite stable with some small fluctuations: gasoline – 1.7-2.0 Mt/y, diesel fuel – 5.1-5.8 Mt/y. The total consumption

[122] The graph is based on statistical data provided by the State Statistics service of Ukraine (SSSU) in publications "Ukraine in figures" and "Statistical Yearbook of Ukraine" for different years. https://www.ukrstat.gov.ua/

of natural gas in the country during 2017-2021 had a slight tendency to decrease; at that, gas consumption in transport reduced by more than twice, from 2.3 bcm in 2017 to 1.0 bcm in 2020. The consumption of liquefied propane and butane was mainly increasing.

Table 4.1. Consumption of motor fuels and natural gas in Ukraine* [123] [124].

Fuel type	2017	2018	2019	2020	2021
Natural gas, bcm, including:	31.5	31.6	27.8	29.9	28.8
- agriculture, forestry and fishery**	0.378 (1.2%)	0.316 (1.0%)	0.250 (0.9%)	0.329 (1.1%)	n/d
- transport, warehousing, postal and courier activities**	2.3 (7.4%)	2.1 (6.6%)	1.0 (3.7%)	1.0 (3.4%)	n/d
Motor gasoline, Mt	2.0	1.8	1.7	1.8	2.0
Gas oils (diesel fuel), Mt	5.1	5.4	5.8	5.2	5.7
Liquefied propane and butane, Mt	0.89	1.0	1.2	1.4	1.3

** Data of enterprises, organizations and institutions on the use of fuel for production-operational and communal-household needs, taking into account the volumes sold to the population and retail sales through filling stations.*
*** Calculated using the original statistical data on "Share of use by individual types of economic activity, percentages".*
***n/d** – no data as Statistical Yearbook of Ukraine for 2021 provides data for 2020, while the previous yearbooks provide data for the year of the yearbook.*

The imports of natural gas during 2017-2020 fluctuated within 9-14 bcm/y (30-40% of the total volume of consumption) with a sharp drop to 3.2 bcm in 2021 (11%) (Table 4.2, Fig. 4.2). Ukraine's own production of natural gas in 2017-2021 was stable at the level of about 20 bcm/y.

Table 4.2. Domestic production and imports of motor fuels and natural gas in Ukraine [125].

Fuel type	Domestic production / Import				
	2017	2018	2019	*2020*	*2021*
Natural gas*, bcm,	20.5/13.9	20.8/10.5	20.5/11.8	20.2/9.1	19.4/3.2
Imports cost, mln USD	3228	3147	2314	1465	3409
Specific imports cost**, USD/1000 m^3	231.5	300.5	197	160	1079
Motor gasoline, Mt	conf. / 1.2	conf. / 1.1	conf. / 1.0	conf. / 1.0	conf. / 1.3
Imports cost, mln USD	689	765	647	400	829
Specific imports cost**, USD/t	555	684	621	393	656
Gas oils (diesel fuel), Mt	conf. / 5.4	conf. / 5.6	conf. / 6.3	conf. / 6.1	conf. / 6.5
Imports cost, mln USD	2792	3742	3925	2441	3896
Specific imports cost**, USD/t	515	669	627	401	599

** Domestic production: liquefied or gaseous natural gas. ** Average cost per year. conf. – data have not been made public since 2015 in order to ensure compliance with the requirements of the Law of Ukraine "On State Statistics" (from 01.01.2023 – the Law "On Official Statistics"[126]) regarding the confidentiality of statistical information.*

[123] Statistical Yearbooks of Ukraine for 2017-2021, SSSU. https://ukrstat.gov.ua/druk/publicat/kat_u/publ1_u.htm
[124] Statistical publication «Ukraine in Figures 2021», SSSU, 2022. https://ukrstat.gov.ua/druk/publicat/kat_u/publ1_u.htm
[125] Statistical publications "Ukraine's Foreign Trade" for 2018-2021, SSSU. https://ukrstat.gov.ua/druk/publicat/kat_u/publ10_u.htm
[126] The Law of Ukraine «On Official Statistics» (№ 2524-IX of 16.08.2022, entry into force took place on 01.01.2023). https://zakon.rada.gov.ua/laws/show/2524-20#n350

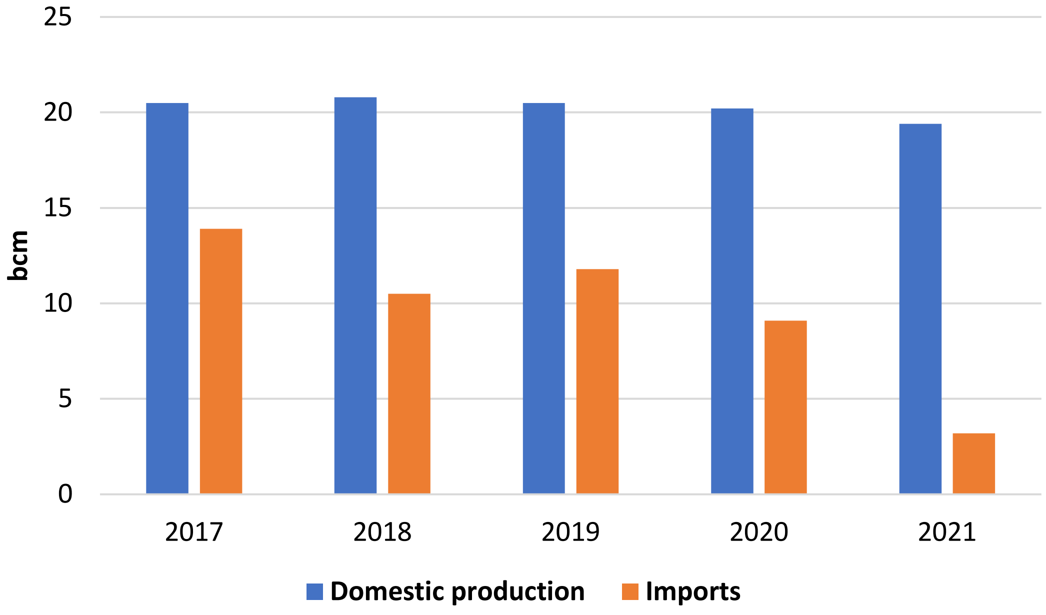


Fig. 4.2. Domestic production and imports of natural gas in Ukraine, bcm

Statistical data on the domestic production of motor gasoline and diesel fuel have not been made public since 2015. However, the comparison of data on imports and annual consumption allows us to conclude that most of these fuels were imported. According to data provided by consulting company "Naftorynok" for 2021[127], imports accounted for 86% of diesel fuel consumption, 55% of gasoline of various brands, and 79% of liquefied gas. Before 2022, the main exporters of motor fuels to Ukraine were Russia and Belarus. At the beginning of 2022, only the Kremenchuk Refinery was operating in Ukraine, but in April 2022 its infrastructure was destroyed by shelling, and the plant ceased its operation.

In 2020, the average annual cost of imported fuels was significantly lower than that in previous years; however, in 2021, the price of imported natural gas rose to 1079 USD/1000 m^3 versus 160 USD/1000 m^3 in 2020. In 2021, 62% of diesel fuel and 50% of gasoline came from Russia and Belarus. Another 10% was imported from Lithuania and by sea, which made up 100% of the imports. After the start of the war on February 24, 2022, the import from Russia and Belarus completely stopped and was reoriented mainly to EU countries[128]. During the second half of 2022, Ukraine received 95% of imported gasoline and 72% of diesel fuel from EU countries. Leaders of the supply were Romania, Lithuania, Slovakia, Greece, Bulgaria and Poland[129].

In 2024, Ukraine considerably changed the geography of gasoline and diesel fuel imports. Poland became the main supplier of gasoline, its share increasing to 52.9% compared to 34.6% in 2023. The second and third places were occupied by Romania (33.9%) and Moldova (11%)[130]. In total, in 2024, Ukraine imported over 1 million tons of gasoline, with 64% of this volume being imported by rail. In 2024, Ukraine imported diesel fuel from 16 countries, the major suppliers being Romania (30%), Poland (26%), and Greece (20%)[131].

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[127] https://www.radiosvoboda.org/a/ukrayina-zabezpechennya-palyvom/31740460.html
[128] https://www.epravda.com.ua/columns/2022/03/20/684340/
[129] https://ua-energy.org/uk/posts/ukraina-narostyla-import-benzynu-v-hrudni-porivniano-z-lystopadom-v-15-razy
[130] https://vnedorozhnik.net.ua/autonews/zvidky-ukrayina-importuvala-ponad-miljon-tonn-benzynu-u-2024-rotsi
[131] https://minfin.com.ua/ua/2025/01/23/143956881/

The largest share of Ukraine's foreign exchange funds (19.7% in 2021) is spent on the import of mineral fuels and petroleum products (**Fig. 4.3**), including 4.7% (3409 mln USD in 2021) on the import of natural gas, 1.1% (829 mln USD) on motor gasoline and 5.3% (3896 mln USD) on diesel fuel (see Table 3.2).

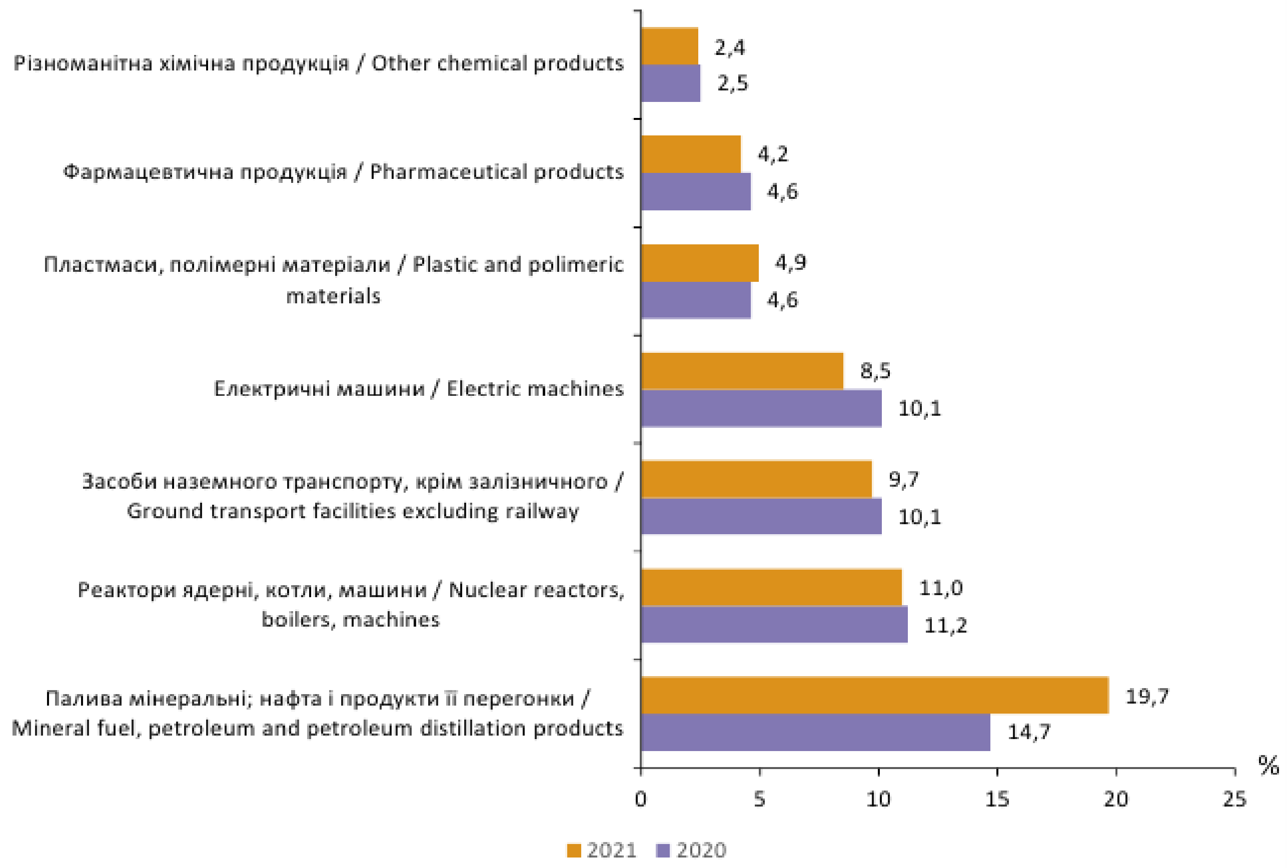


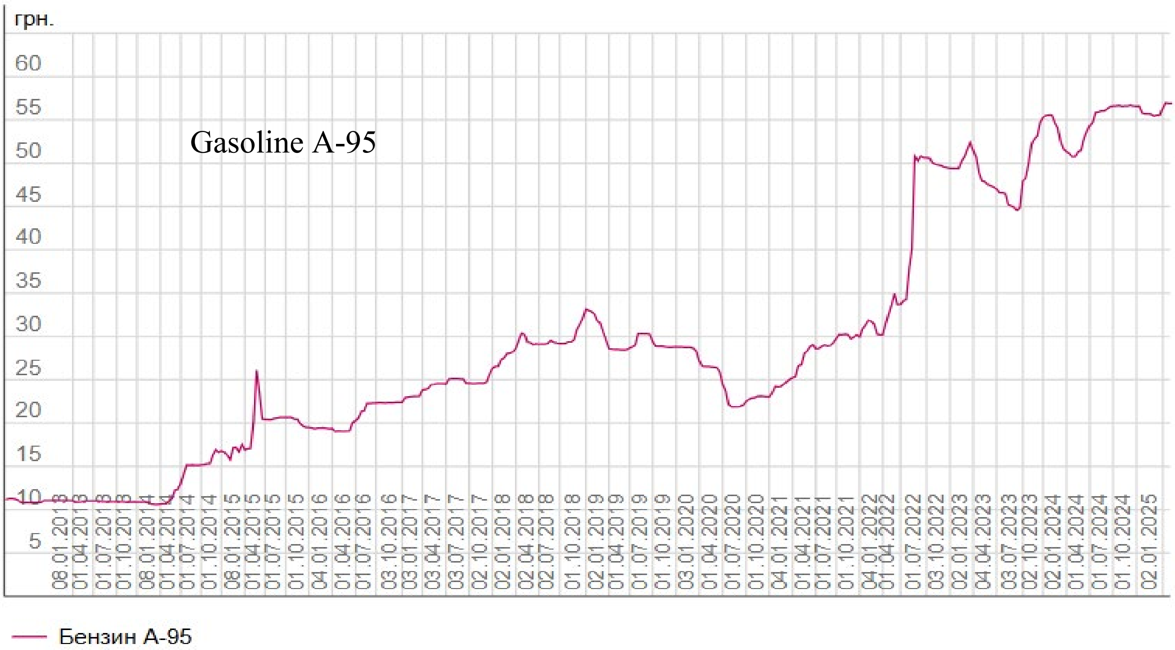
Fig. 4.3. Commodity structure of imports in 2020-2021 (**%**)

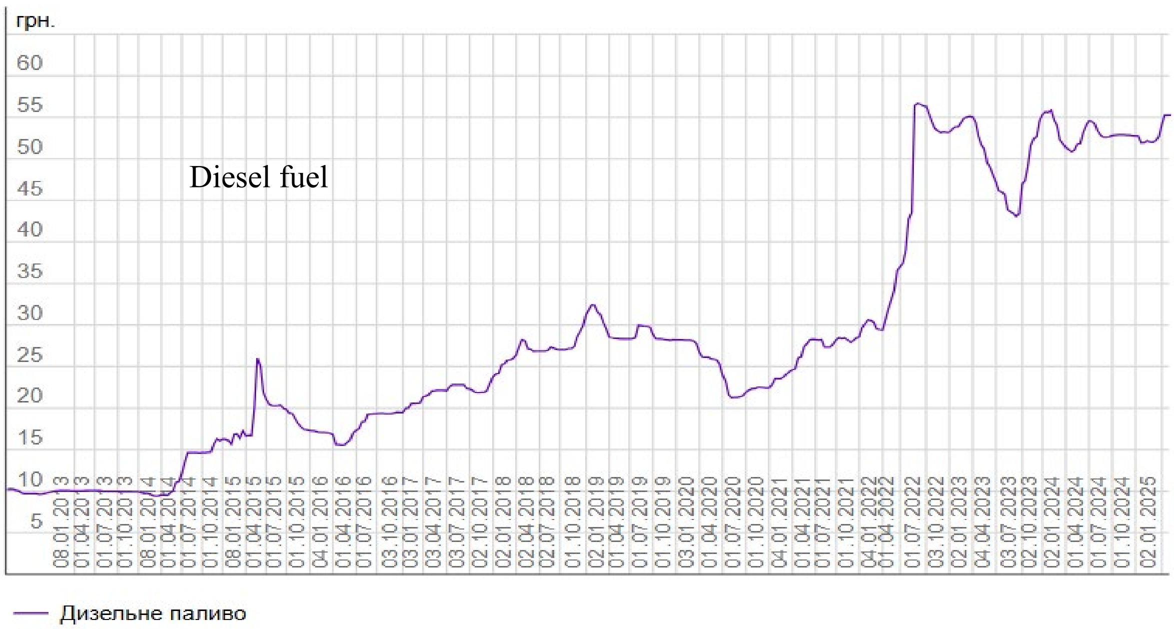
Expert estimation shows that after the war began in February 2022, the consumption of motor fuels in Ukraine fell sharply compared to 2021: diesel fuel by almost 2.5 Mt, gasoline by a third, liquefied gas by nearly two times [132]. This is primarily due to the cessation of imports from the Russian Federation and Belarus, the blockade of sea routes, missile attacks on fuel and energy infrastructure, and the establishment of new ties with suppliers in Europe. Though 2023 became a year of growth, especially for diesel fuel as the most popular one, in two years, gasoline lost 16% of its consumption, liquefied gas 34%, and diesel fuel 17% of the 2021 level[133]. In 2024, the Ukrainian fuel market continued to demonstrate stability and improve after radical changes caused by the refusal of Russian and Belarusian supplies[134]. This year became a turning point in the systematization of import channels and strengthening cooperation with reliable international partners. In 2024, there was stability in gasoline imports (1.24 Mt) and an increase in diesel fuel imports by 7.5% (up to 6.6 Mt). At the same time, imports of liquefied petroleum gas (LPG)

[132] https://www.ukrinform.ua/rubric-economy/3803255-cogoric-v-ukraini-pocalo-zrostati-spozivanna-palnogo-ekspert.html?utm_source=chatgpt.com
[133] https://fin.informator.ua/uk/spozhivannya-palnogo-v-ukrajini-zrostaye-ekspert-poyasniv-shcho-ce-znachit
[134] https://enkorr.ua/uk/news/2024_rk_stav_rokom_vdoskonalennya_palivnogo_rinku_ukrani_sergy_kuyun/262068?utm_source=chatgpt.com

decreased by 7.2% (up to 900 kt). These trends are associated with the growth of freight transportation and a decrease in fuel consumption by individuals.

Changes in motor fuel supply routes and consumption volumes have affected their prices in Ukraine. In Fig. 4.4, one can see the obvious sharp increase in the prices in summer 2022 with further general price rise for gasoline, comparative stabilization for diesel fuel and strong fluctuations for LPG.





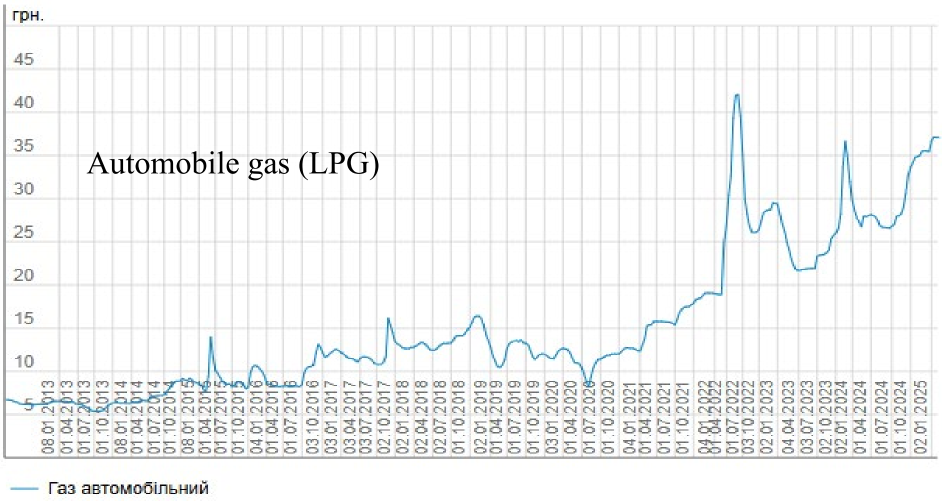


Fig. 4.4. Dynamics of prices of gasoline[135], diesel fuel[136] and automobile gas (LPG)[137] at the filling stations in Ukraine (2013-2025), UAH/l.

In Ukraine, there have been traditions and experience of using compressed natural gas (CNG) as a motor fuel for buses and heavy vehicles. Methane is used in transport in a compressed form up to 200-250 atmospheres. This form of storage requires bulky and heavy containers – cylinders with thick walls. Therefore, the absolute majority of conversions to methane are trucks and buses[138]. There is a network of CNG filling stations in Ukraine with more than 260 units, which are located mainly in large cities and along transport highways. Unfortunately, the volume of methane sales at CNG filling stations had trends towards decrease due to the small number of vehicles that used this gas as fuel. According to unofficial statistics, the fleet of methane-powered vehicles in Ukraine does not exceed 30,000 units[139], though in 2005-2006 their number came to nearly 90,000 (Fig. 4.5).

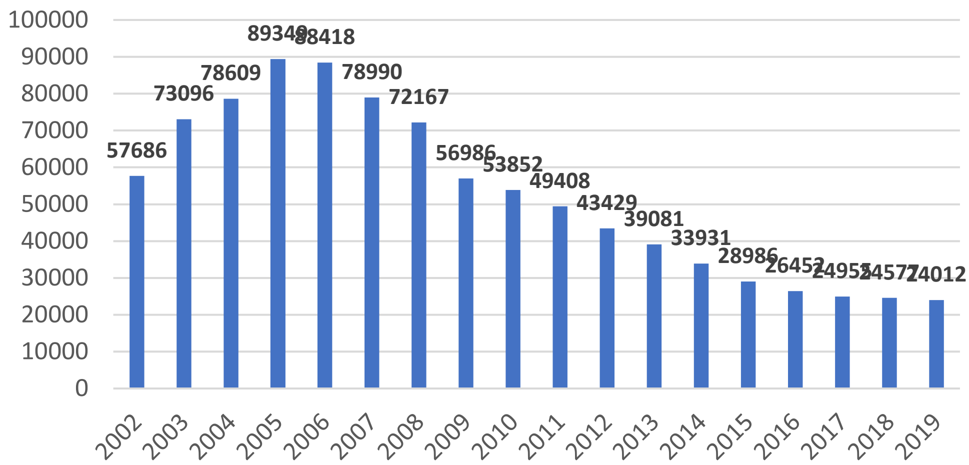


Fig. 4.5. Dynamics of the number of CNG vehicles in Ukraine, units[140]

135 https://index.minfin.com.ua/ua/markets/fuel/a95/
136 https://index.minfin.com.ua/ua/markets/fuel/dt/
137 https://index.minfin.com.ua/ua/markets/fuel/lpg/
138 https://auto.24tv.ua/avtohaz_vydy_kharakterystyky_krashchyi_haz_dlia_avto_n27926
139 https://biz.nv.ua/ukr/experts/gaz-na-avto-gbo-ekonomichno-dlya-vlasnikiv-chisto-dlya-navkolishnogo-seredovishcha-vigidno-dlya-ukrajini-50036086.html
140 https://www.liga.net/ua/all/opinion/chas-povertatysia-do-hazomotornoho-palyva-os-chomu

“Ukravtogaz” is a subsidiary of the National Joint-Stock Company "Naftogaz of Ukraine". Main activity of " Ukravtogaz " is the operation of 90 automobile gas filling compressor stations (AGNKS) throughout Ukraine with a total capacity of 687.5 million m^3 [141]. The sales of CNG started with about 300 mln m^3/y in 2002, peaked at 450 mln m^3/y in 2005-2006, after which gradually decreased to less than 50 mln m^3/y in 2018-2019 (Fig. 4.6). The network of CNG filling stations was shut down in 2022 amid a sudden increase in natural gas prices. However now, “Ukravtogaz” is resuming the operation of its CNG filling station network in major cities of Ukraine, the current price of CNG being ~31 UAH/m^3 (0.72 EUR/m^3) [142, 143, 144].

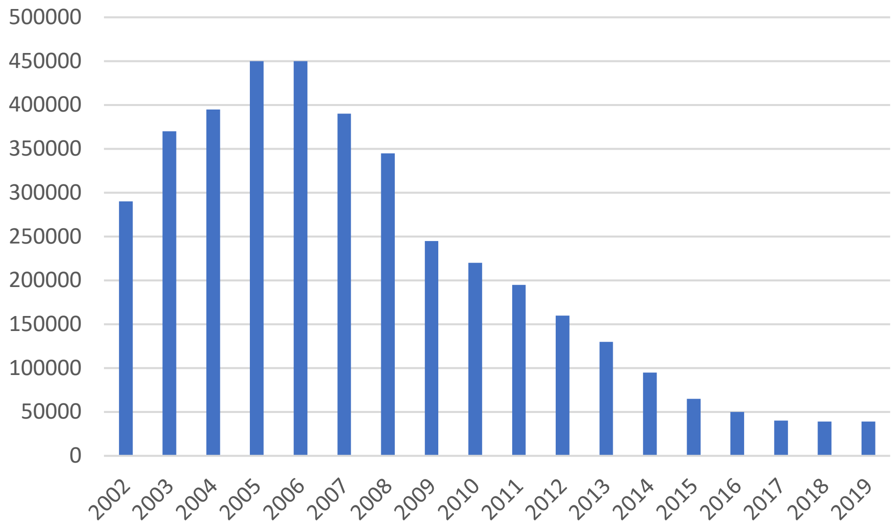


Fig. 4.6. Evolution of CNG sales through AGNKS network operated by “Ukravtogaz”, 1000 m^3 [145]

CNG has quite good prospects in Ukraine, especially in commercial and public transport. Infrastructure development, government support and economic benefits can contribute to the active expansion of this market segment. However, for mass implementation it is necessary to solve the problems with filling stations, high cost of equipment and development of gas storage technologies.

Liquid and gaseous biofuels

In recent years before the war (2022), the production and consumption of bioethanol in Ukraine were relatively low: in particular, about 140 kt of bioethanol were consumed in 2019 and 81 kt in 2020 (Table 4.3). In addition, the exports of bioethanol to the EU amounted to 8 Ml in 2020 and 35 Ml in 2021. The production and consumption of biodiesel fuel in Ukraine are practically absent, and the use of biogas/biomethane in transport sector has not been implemented yet.

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141 https://ukravtogaz.com/
142 Exchange rate EUR/UAH is 42.98 as of 07.02.2025 according to the National Bank of Ukraine https://bank.gov.ua/en/
143 https://www.nefterynok.info/novosti/ukravtogaz-vdnovlyu-robotu-merej-agnks
144 https://ukravtogaz.com/news
145 https://ukravtogaz.com/news/onovlennya-sistemi-upravlinnya-dp-ukravtogaz-pershi-dosyagnennya-ta-rezultati.html

Table 4.3. Consumption of bioethanol, biodiesel and biogas on transport in Ukraine[146].

Type of biomass fuel	2014	2015	2016	2017	2018	2019	2020
Bioethanol, ktoe	42.4	35.1	38.4	47.0	37.2	88.1	51.1
kt	67.3	55.7	60.9	74.6	59.0	139.8	81.1
Biodiesel, ktoe	-	-	-	-	-	-	-
Biogas, ktoe	-	-	-	-	-	-	-

Nevertheless, the *National Renewable Energy Action Plan until 2030 (NREAP)*[147] (approved in 2024) sets quite ambitious goals for the development of Ukraine's sector of motor biofuels, except for biomethane (Table 4.4). In contrast with the official NREAP figures (1 ktoe of biomethane in transport in 2030), experts of the Bioenergy Association of Ukraine (UABIO) assess the use of biogas/biomethane in transport at 10 ktoe/y in Ukraine in 2030 with further increase to 830 ktoe/y in 2050[148].

Table 4.4. Annex 6 to NREAP 2030: CALCULATED SHARE of renewable energy in the transport sector, ktoe

Type of renewable energy consumed in the transport sector	2020	2025	2026	2027	2028	2029	2030
RENEWABLE ELECTRICITY, including:	44	141	201	262	313	403	409
electric cars		35	49	63	74	81	81
railway transport	35	52	65	80	92	88	85
other types of electric transport	8	54	87	119	148	234	242
BIOFUELS, including:	51	0.1	75	155	240	327	420
Bioethanol:	51	0.1	73	152	233	318	408
Biodiesel:			2	4	6	8	12
BIOMETHANE, including:							1
biomethane from food and feed crops							
biomethane from waste, residues (advanced)							0.5
biomethane from methanation of hydrogen and biogenic CO_2							0.5
Total consumption of renewable energy in the transport sector	95	142	276	417	553	730	830
Total contribution of renewable energy to achieving the indicative RES target in the transport sector[1)]	148	273	449	652	831	1029	1138

1) Taking into account the multiplication factors (for 2020 – according to Directive 2009/28/EC, for 2025-2030 – according to Directive 2018/2001).

[146] Reports on the Promotion and Use of Energy from Renewable Sources in Ukraine in 2014-2020, SAEE. https://saee.gov.ua/uk/content/informatsiyni-materialy
[147] https://zakon.rada.gov.ua/laws/show/761-2024-%D1%80#Text
[148] Road Map for Bioenergy Development in Ukraine until 2050, UABIO Position Paper № 26. https://uabio.org/en/materials/9115/

Ukraine has the largest area of agricultural land in Europe and, therefore, one of the best world's potentials of agricultural feedstock for biomethane production. In addition, Ukraine has a developed network of gas distribution networks and a powerful gas transportation network, which allows biomethane producers to connect to gas networks in most parts of Ukraine. Transporting biomethane through the gas networks and using biomethane in gas equipment (gas burners, engines, turbines) does not require costs for their modernization[149].

Biomethane is one of the most cost-effective ways to decarbonize the energy sector and the economy. Using biomethane as a motor fuel allows agricultural producers to obtain their own source of energy from waste and residues of their own production. The use of biomethane in public transport can significantly reduce air pollution in large cities. It is advisable to use biomethane not only in road transport, but also in water and rail transport, and not only in compressed but also in liquefied form.

However, it should be noted that when choosing between biomethane and natural gas, the owner of a car in Ukraine is more likely to prefer the latter, since there is already a network of gas stations on natural gas, the price of which is notably lower than the economically justified selling price of compressed biomethane. In addition, there are no additional benefits or incentives for biomethane refuelling at this time[150].

4.2 Road vehicle's structure

According to the data of the Main Service Centre of the Ministry of Internal Affairs in Ukraine, about 11.7 million vehicles were registered. Gas fuel (LPG/CNG) can use about 2 million units of transport (**Table 4.5**). Every 5 cars (1,921,101 units) can use gas fuel, compared to 10% of trucks (146,450 units) and 15% of buses (24,929 units). Only 560 garbage trucks (8%) out of 6831 can use gas fuel. Thus, the main type of vehicle that can run on gas fuel is cars - 92% of the total.

Table 4.5. Structure of registered transport in Ukraine, March 2025

№	Name	Quantity	LPG/CNG	% on LPG/CNG
1	Trucks	1 465 807	146 450	10%
2	Cars	10 100 742	1 921 101	19%
3	Buses	170 672	24 929	15%
	Total	**11 737 221**	**2 092 480**	**18%**

The register of vehicles contains generalized information about vehicles on gas fuel and, unfortunately, there is no detailed information about the type of gas (LPG or CNG) in the registers. Therefore, it is not known for certain how many and what type of vehicles LPG or CNG uses. It can be assumed that most buses and trucks use CNG, which corresponds to 70-100 thousand units of vehicles. At the same time, cars usually use LPG and the total number can be 1.6-1.8 million units.

Import and re-equipment of gas fuel vehicles

The number of motor vehicles registered depends on the number of vehicles produced in Ukraine, imported and re-equipped. In 2024, more than 367,000 were registered, and in 2023 – 386,000 vehicles. On average, 3-5% of imported cars can use gas fuel.

[149] https://epravda.com.ua/columns/2021/04/15/673050/
[150] https://saf.org.ua/en/news/624/

In the period of 2020-2024, from 32,000 to 63,000 vehicles operating on fuel gas were registered (**Table 4.6**). The share of passenger vehicles is dominant and amounts to more than 95% of the total (**Table 4.7**). Gas-fuelled trucks are registered from 385 units to 1,120 units, buses to 132 units. The share of converted cars for the use of fuel gas is decisive and is 65% in 2024 (20,459 units) and 75% (49,257 units) in 2023.

Table 4.6. Vehicle registration structure by type of registration (gas fuel)

Type of registration	2020	2023	2024
Re-equipped	28 969	37 668	20 459
Primary registration (import)	34 112	12 220	11 296
Primary registration (in Ukrainian)	95	31	22
Total	**63 176**	**49 919**	**31 777**

Table 4.7. Dynamics of transport registration in Ukraine (gas fuel)

Type	2020	2023	2024
Cars	61 924	49 257	31 368
Trucks	1 120	648	385
Buses	132	14	24
Total	**63 176**	**49 919**	**31 777**

The main share of road transport can use gasoline or fuel gas at the same time and the owners of such vehicles are individuals (95%). An odd share of cars can work exclusively on gas fuel (**Table 4.8**, **Table 4.9**). Only single cases of diesel and hybrid electric vehicles have been registered where gas fuel can be used. This practice is not common.

Table 4.8. Structure of vehicle registration by type of fuel (gas fuel)

Type of fuel	2020	2023	2024
Gasoline or gas	59 201	48 503	30 397
Gasoline, gas or electro	222	613	649
Gas	3 732	790	731
Gas and electro	4	2	
Diesel fuel or gas	17	11	
Total	**63 176**	**49 919**	**31 777**

Table 4.9. Vehicle registration structure by vehicle ownership type (gas fuel)

Type of ownership	2020	2023	2024
Private	60 573	49 027	31 030
Legal entities	2 603	892	747
Total	**63 176**	**49 919**	**31 777**

Table 4.10 shows the TOP 5 most common passenger and freight types of road transport registered in 2020-2024. Among passenger vehicles, the most common are cars in the wagon and sedan. Vans with a carrying capacity of up to 3.5 tons, dump trucks and pickups are the most common types of gas-powered trucks that have been registered.

IVECO, MAN buses using gas fuel are the most common among those registered in 2020-2024. About 30% of registered trucks are GAZ brand cars (Russian Federation) of the 1974-2020 model (**Table 4.11**). More than 35% of trucks are over 25 years old, 35% are under 10 years old and only 11% of cars are under 5 years old. Most gas-fuelled trucks were registered in city of Kyiv, Kyiv, Dnipropetrovsk and Kharkiv regions, a total of 32-38% for 2020-2024.

Table 4.10. Vehicle registration structure by body type. TOP 5 (gas fuel)

Type of body	2020	2023	2024
Cars			
Wagon		26 230	18 117
Sedan		15 008	8 583
Hatchback		7 564	4 397
Compartment		133	86
Passenger	308	169	79
Trucks			
Van up to 3.5 tons	58	285	142
Dump truck	125	104	84
Onboard	36	72	40
Pickup	82	72	37
Airborne-tented	67	25	20

Table 4.11. Structure of registration of vehicles by brand. TOP 10 (gas fuel)

Type of brand	2020	2023	2024
Buses			
IVECO			11
MAN			6
GAZ	2	4	3
MERCEDES-BENZ		3	2
RUTA	2	3	1
IC CORPORATION			1
UAZ	1	2	
SOLARIS		1	
FORD		1	
PAZ	2		
Trucks			
GAZ	282	151	105
FIAT	43	72	26
SAZ	24	39	25
RAM	4	33	21
VOLKSWAGEN	6	20	21
ZIL-MMZ	41	22	18
ZAZ	43	33	16
ZIL	48	40	16
FORD	14	24	16
GAZ-SAZ	23	12	16

4.3 Potential agricultural consumption of biomethane

Agriculture is one of the most important and successful sectors of the economy of Ukraine. In the structure of the gross domestic product (GDP) in 2023, the share of agriculture, forestry and fishing was the third (9.0%) after public administration; compulsory social security (20.3%) and trade (12.7%)[151]. The GDP in Ukraine was worth 178.76 billion US dollars in 2023, according to official data from the World Bank[152]. In pre-war 2021 the share of agriculture, forestry and fishing in GDP was second with 10.4% after trade (13.5%). Crop production made up 81.1% of all agricultural output in 2023, including the production of grain and leguminous crops – 33.6%, industrial crops – 33.4%[153]. At the same time, enterprises produced 73% of crop production and 58% of animal products. The rest of these products is produced in households.

To perform mechanized operations, agriculture uses significant amounts of fuel, mainly diesel fuel, especially in enterprises that produce crop products. For drying grain and oilseeds, agriculture consumes large volumes of natural gas. In addition, significant motor fuel consumption is associated with the transportation of commodities to the global market such as cereal grains and oilseeds. According to the Energy Balance of Ukraine for 2020[154], the final annual consumption of fuel and energy in the agriculture of Ukraine amounted to 1669 ktoe, including the consumption of petroleum products – 1016 ktoe (61% of the total) (**Fig. 4.7**). Approximately the same level of energy/fuel consumption (with certain fluctuations) has been over the past 20 years (**Fig. 4.8**). Statistical data on fuel consumption from the State Statistical Service of Ukraine since the beginning of the war in 2022 have not been available.

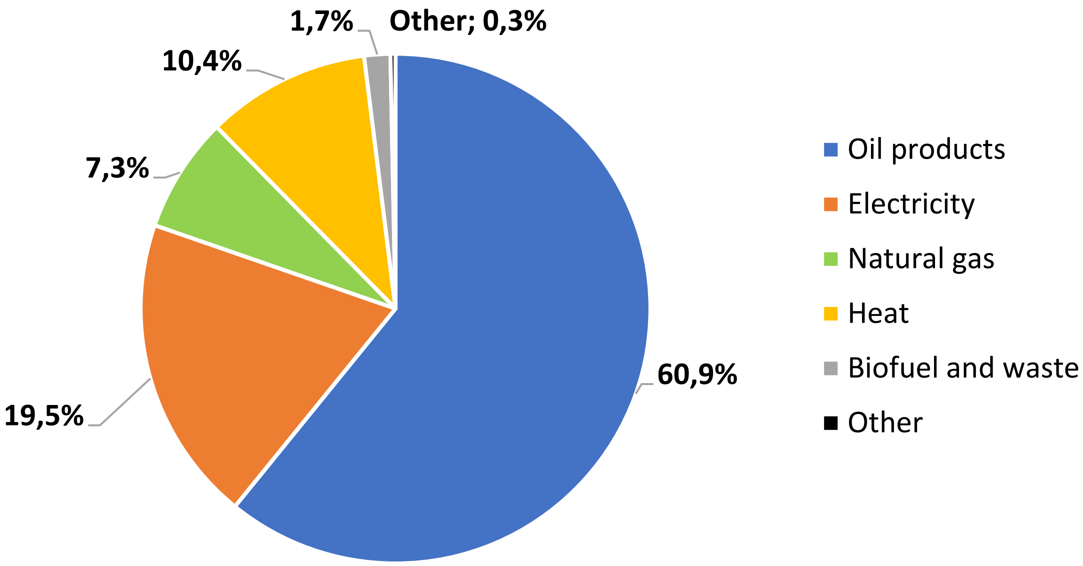

Fig. 4.7. Structure of the final fuel and energy consumption in Ukraine's agriculture (2020).

[151] https://www.ukrstat.gov.ua/operativ/operativ2020/vvp/vvp_rik/vtr_rik10-23_2021_100.xlsx
[152] https://data.worldbank.org/country/ukraine
[153] https://www.ukrstat.gov.ua/druk/publicat/kat_u/2023/zb/11/year_23_u.pdf
[154] Ukraine's Energy Balances, SSSU. https://ukrstat.gov.ua/operativ/menu/menu_u/energ.htm

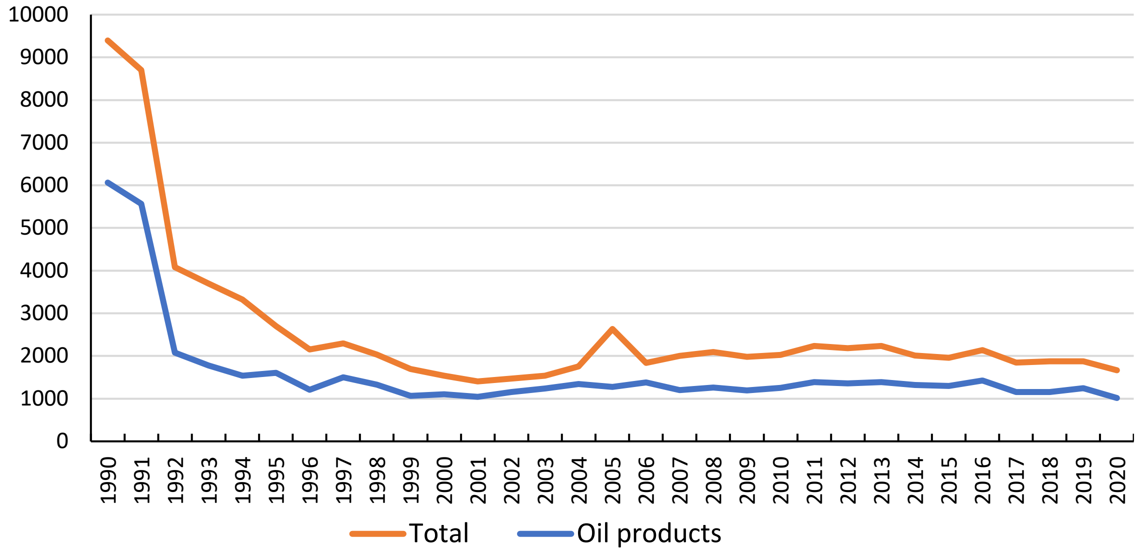

Fig. 4.8. Dynamics of the final fuel and energy consumption in Ukraine's agriculture, **ktoe**.

In 2020, agriculture was one of the largest consumers of gasoline and diesel fuel in Ukraine (> 23% of the total volume of diesel and 5% of gasoline). Other large consumers are industry (15-20% of diesel, 6% of gasoline) and the transport and communications industry (19-24% of diesel, 2.4-4% of gasoline)[155]. The final consumption of **gas oils/diesel** in agriculture amounted to **983** kt in 2020 and 1100-1300 kt/y for several previous years (**Table 4.12**).

Table 4.12. Final consumption of fuel and energy in agriculture of Ukraine according to the Energy Balance of Ukraine (by products)[156].

Type of fuel/energy	2016	2017	2018	2019	2020
Not coking coal / anthracite, kt	13	13	12	11	8
Coal briquettes, peat, kt	1	1	1	2	2
Natural gas, TJ	6449	6115	5684	4443	5682
LPG (propane, butane), kt	19	21	15	17	14
Gas oils/diesel, kt	1378	1108	1130	1216	983
Motor petrol*, kt	-	-	-	-	-
Fuel oil, kt	1	1	2	-	0
Other oil products**, kt	3	1	2	-	-
Solid biomass fuel, TJ	825	1063	1538	1156	1158
Electricity, GWh	3513	3642	3868	3675	3777
Heat, TJ	10210	9114	9150	7854	7270

*** Data on the final consumption of motor petrol in agriculture are not available (blank) in the Energy Balance of Ukraine (by products).*
*** Calculated data.*

The types of motor fuel most used in agricultural production are **diesel fuel** and **gasoline**. Their consumption is priority for mobile technological processes used in crop production. Usually, more

[155] AGRO TIMES https://bit.ly/3X9DTV
[156] Energy Balances of Ukraine (by products), SSSU. https://ukrstat.gov.ua/operativ/menu/menu_u/energ.htm

than 85% of diesel fuel is spent for agricultural operation and up to 15% for transport operations. At that, the consumption of automobile gasoline comes to 56% for transport operations and to 43.1% for agricultural operations[157]. Agricultural enterprises reduced their use of gasoline by 13 times as compared to 1990, and diesel fuel by three times. This can be explained by the reduction of sown areas by almost 15%, cultivation of less energy-intensive agricultural crops, reduction by almost four times of the fleet of cars, tractors and combines, as well as a significant decrease in the animal husbandry production. Decreasing fuel consumption contributed to the reduction of energy intensity of agricultural products. In 1994, agricultural enterprises spent 44.7 kg of equivalent fuel per 1000 UAH of gross output in comparative prices of 2010; in 2018, this index is only 11.5 kg, which is 3.9 times less.

In 2020, agricultural enterprises of Ukraine purchased **85.4** kt of motor **gasoline** at an average price of 19,980.7/t UAH (740 USD/t), and 1301.3 kt of **diesel fuel** at an average price of 16,466.1/t UAH (609.9 USD/t) (**Table 4.13**). In March 2025, retail prices for diesel fuel and gasoline A92 are 55.29 UAH/l and 54.09 UAH/l[158] or 65821 UAH/t (1582.6 USD/t) and 72120 UAH/t (1734 USD/t), respectively. Therefore, current motor fuel prices are 36.4 USD/GJ for diesel and 40.3 USD/GJ for gasoline. At the same time, the commercial price of natural gas is 24,000 UAH/1000 m^3 or about 17 USD/GJ, which creates the prerequisites for converting agricultural machinery to gas fuel. However, it should be noted that the use of methane requires additional costs, such as the purchase of refuelling equipment, methane compression/liquefaction, and costs for conversion of machines. This is described in more detail in Section 3 of this report. From the data in the table, one can see that the volumes of diesel fuel purchases have been relatively stable in recent years, while the purchase of gasoline by agricultural enterprises has been constantly decreasing.

Table 4.13. Purchase of gasoline and diesel by Ukrainian agricultural enterprises in 2016-2020 [159].

Type of fuel	2016	2017	2018	2019	2020
Motor gasoline:					
quantity purchased, kt	145	125.3	109.3	101.0	85.4
average price, UAH/t	18602	22750	27123.8	25185	19980.7
average price*, USD/t	726.6	855.3	997.2	976.2	740.0
acquisition costs*, million USD	105.4	107.2	109.0	98.6	63.2
Gas oils (diesel fuel):					
quantity purchased, kt	1378[155]	1345.4	1445	1454.7	1301.3
average price, UAH/t	15038	18948.8	23863.2	21488.2	16466.1
average price*, USD/t	587.4	712.4	877.3	832.9	609.9
acquisition costs*, million USD	809.4	958.5	1267.7	1211.6	793.7
Note: * Exchange rate, UAH to USD (average)[160]	25.6	26.6	27.2	25.8	27.0

[157] Vyshnevetska O.V. Consumption of fuel and energy by agricultural enterprises // Innovative economy, № 5-6, 2020. http://inneco.org/index.php/innecoua/article/view/630
[158] https://index.minfin.com.ua/ua/markets/fuel/
[159] Purchase of material and technical resources by enterprises for production needs, SSSU. https://ukrstat.gov.ua/operativ/operativ2018/sg/pr_mt_res/arh_pr_mt_res_u.htm
[160] https://bank.gov.ua/files/Exchange_r.xls

According to the calculations of the Institute of Agrarian Economics[161], **in 2023, the total consumption of diesel fuel in agriculture in Ukraine amounted to 972 thousand tons**. This is 33% less than in pre-war 2021. The same reduction applies to gasoline. In 2022, fuel consumption was even lower – 900 thousand tons and 60 thousand tons, respectively. **Agricultural enterprises consume over 29% of diesel fuel the total amount of its consumption in Ukraine, while gasoline – 7%.**

Over 20 years, fuel consumption per 1,000 hectares of agricultural land has decreased by 3.4 times and amounted to 50 tons of fuel equivalent in 2022. **To purchase fuel, agricultural enterprises must annually sell an increasing amount of agricultural products.** If in 1995 one ton of diesel fuel cost 2.7 tons of grain, then in 2022, it will be 9.8 tons, that is, 3.7 times more. Even compared to 2021, this figure has doubled. A similar trend persists for all types of agricultural products.

As of January 1, 2020, the area of agricultural land was 41.3 million hectares (about 70% of the total territory of Ukraine), including 32.8 million hectares of arable land. Of the total sown area of agricultural crops (28.6 million hectares in 2021), the largest shares fall on cereals and legumes (56%, including wheat – almost 25%, corn – 19%) and industrial crops (32%, including sunflower – 23%, rapeseed – 3.5%).

The general trend of the last 10-15 years before the war is an increase in the yield of the main agricultural crops (with certain fluctuations from year to year), as well as a significant increase in the production of grain and leguminous crops (in particular, wheat and corn) and sunflower. **In 2019, the Ukrainian agricultural sector had more than 310,000 tractors (including 130,500 ones at enterprises)** and more than 40,000 combine harvesters (including 26,500 ones at enterprises)[162]. In addition, agricultural enterprises used about 79,000 trucks and cargo-passenger vehicles. The hostilities significantly affected the agricultural machinery market in Ukraine, limiting access to new tractors and combines for farmers.

Following the full-scale Russian invasion, crop area decreased by 21% (**Fig. 4.9**). In addition, the structure of crops has changed. The planted area of agricultural crops under the harvest of 2024 was 23.2 million hectares. The largest areas were occupied by sunflower – 4.95 million hectares; wheat – about 4.90 million hectares; corn for grain – 4.05 million hectares; soybeans - 2.66 million hectares; barley – 1.41 million hectares; rapeseed – 1.27 million hectares[163].

During the war, the amount of losses of the Ukrainian agricultural sector was USD 10.3 bln in 2022-2023 and indirect losses were USD bln 69.8 in 2022-2024. **Agricultural machinery was the most affected, especially tractors, of which over 18,000 were destroyed. In 2022–2023, the amount of losses of agricultural machinery was USD 5.8 bln.** Significant damage was caused to grain elevators, with a total loss of capacity of 19.5% (excluding those inaccessible due to occupation)[164].

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[161] https://www.growhow.in.ua/ahrarnyy-sektor-ie-osnovnym-spozhyvachem-palnoho-v-ukrainskiy-ekonomitsi/
[162] Statistical publications Agriculture of Ukraine 2017, 2020, 2021. https://ukrstat.gov.ua/druk/publicat/kat_u/publ7_u.htm
[163] https://ukrstat.gov.ua/operativ/operativ2021/sg/ppsgk/ppsgk2024.xls
[164] Agribusiness of Ukraine 2023/2024. https://agribusinessinukraine.com/the-infographics-report-ukrainian-agribusiness-2024-eng/utm_source=latifundist&utm_medium=threads/

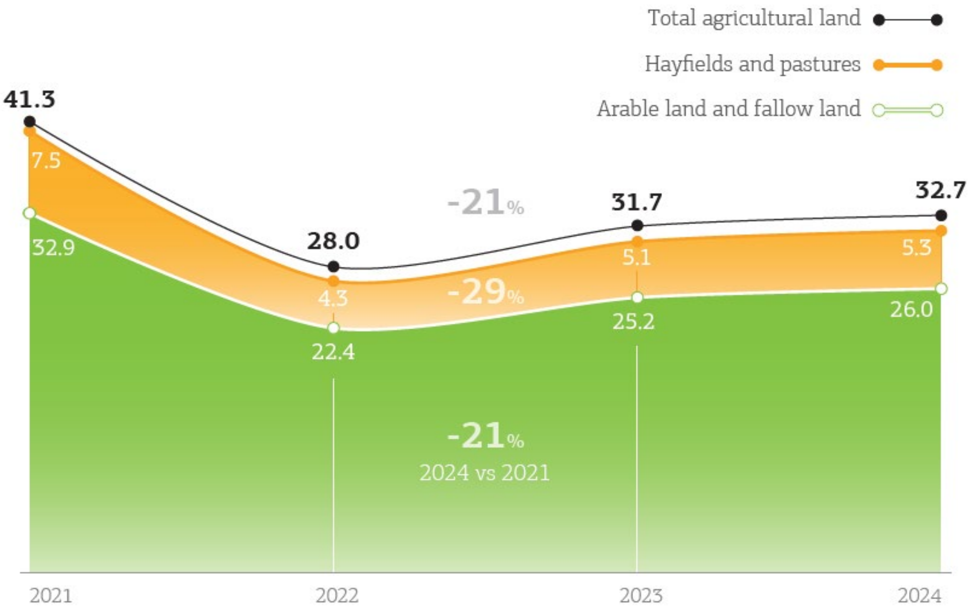


Fig. 4.9. Dynamics of Ukraine's land resources, mln ha

Thus, it can be expected that agriculture in Ukraine in the near future will maintain consumption of up to 1 million tons of diesel fuel and about 60,000 tons of gasoline per year. Biomethane can be used as fuel in existing diesel and gasoline engines in agriculture, considering that there are significant waste and residual biomass resources for biomethane production. This requires certain measures for the engines. The total energy equivalent of biomethane for the replacement of motor fuels in Ukrainian agriculture is about 1.3 bcm of CH_4.

In diesel engines, the fuel system needs to be modified to use gas. This includes installing special injectors to supply biomethane and adjusting the air-gas mixture system. Diesel engines operate on the principle of self-ignition, but to run on biomethane, external ignition, such as spark plugs, must be used, as in gasoline engines.

Gasoline engines already have a fuel system suitable for working with gas, so you only need to install special gas injectors and adjust the air-gas mixture system. In addition, special tanks must be used. However, taking into account the delayed demand for tractors, combines and other machines in the agricultural sector of Ukraine, new equipment can be purchased that is immediately developed for the use of biomethane.

For example, there are tractors running on CNG: a New Holland T6.180 Methane Power 150 hp tractor on 100% biomethane (**Table 4.14, Fig. 4.10a**) and AUGA M1 Hybrid 500 hp Tractor with hybrid biomethane-electric fuel system (**Fig. 4.10b**). The gas-powered T6 will cost more or less the same as the standard diesel version[165]. There is also a tractor on LNG. At the Agritechnica 2023 agricultural machinery exhibition, New Holland showed a pre-production prototype of the T7 Methane Power LNG tractor with a capacity of 270 hp, which has fourfold increase in fuel capacity compared to the T6 Methane Power CNG.

A preliminary feasibility study for the introduction of CNG and bio-CNG compared to diesel fuel for fuelling a 150-horsepower tractor is presented in **Table 4.15**. As can be seen, at current prices for natural gas, diesel fuel, and the expected price of biomethane, switching from diesel to LNG can result in a 29% cost reduction while switching to biomethane will be unprofitable. Therefore,

[165] https://www.futurefarming.com/smart-farming/new-holland-t6-180-methane-tractor-soon-to-be-available/

to implement an economically viable transition to biomethane, financial incentives need to be introduced that monetize emission reductions and sustainability in the use of biomethane.

Table 4.14. Technical specifications New Holland T6 Methane Power[166].

MODEL	T6.180
New Holland Engine, developed by FPT Industrial	6 Cylinder Nef, 6728 cm^3
Compliant with engine emissions regulations	Above Stage V
Max. EPM horsepower - ISO TR14396 - ECE R120	129 kW / 175 hp
Rated horsepower - ISO TR14396 - ECE R120	110 kW /150 hp
Rated engine speed	2200 rpm
Methane tank capacity (tractor/range extender)	185 l /270 l
Service interval	600 hours
Typical working weight	6290 kg / 6540 kg
Max. permissible weight	10500 kg / 10500 kg

a - New Holland T6.180 Methane Power

b - Auga M1 Hybrid tractor[167]

Fig. 4.10. Methane tractors

Table 4.15. Feasibility study for the introduction of tractors running on CNG and bio-CNG

Indicators	Units	CNG	Bio-CNG
Annual tractor loading	hours/year	1500	
Diesel tractor			
Specific CNG consumption	l/hour	17.5	
AdBlue	l/hour	1.2	
Diesel fuel price	EUR/l without VAT	1.0	
AdBlue price	EUR/l without VAT	0.6	
Annual diesel fuel consumption	l/year	26250.0	
Annual fuel cost + AdBlue	EUR	28234.6	
Methane tractor			
Specific CNG consumption	kg/hour	15.3	
Annual CNG consumption	kg	22996.1	
Methane price	EUR/1000m^3 without VAT	460.0	750.0

[166] https://assets.cnhindustrial.com/nhag/eu/en-uk/assets/pdf/agricultural-tractors/t6-180-brochure-uk-en.pdf
[167] https://www.futurefarming.com/tech-in-focus/auga-group-halts-development-of-hybrid-auga-m1-tractor/

Indicators	Units	CNG	Bio-CNG
CNG cost	EUR/kg without VAT	0.8	1.3
Additional costs for CNG*	EUR/kg without VAT	0.1	
Annual cost of CNG	EUR	20063.8	31223.2
Cost reduction for CNG compared to diesel	*EUR*	*8170.8*	*-2988.6*
Reduction amount in %	%	29%	-11%
* Operating costs from option 4 in Table 3.7 are taken into account			

Manufacturers of cargo vehicles are offering models such as *Scania Gas Trucks* that run on both compressed and liquefied biomethane. Also, on the market, there are kits for using methane in internal combustion engines. For example, Optiblend dual fuel: Diesel – Natural Gas Conversion Kit has been installed on Caterpillar, Cummins, Kohler, MTU, John Deere, Mitsubishi, and many other diesel engines[168]. Thus, the agricultural sector has the opportunity to purchase specialized new tractors and trucks running on methane/biomethane or to convert existing internal combustion engines to dual fuels: liquid motor fuel/gas.

Biogas/biomethane presents a viable alternative to diesel and gasoline in agriculture, particularly for regions with abundant biomass waste resources. While the transition involves challenges such as infrastructure development and initial costs, the long-term benefits include reduced emissions, enhanced energy security, and cost savings. Dual-fuel engines offer a practical pathway for gradual adoption by combining the reliability of diesel with the sustainability of biomethane.

The National Renewable Energy Action Plan until 2030[169] identifies biomethane as an important source of renewable energy. It can be used to directly replace natural gas in the production of thermal and electrical energy. In the transport sector, biomethane can replace various types of motor fuels: compressed natural gas (CNG), gasoline, diesel, liquefied natural gas (LNG), and liquefied petroleum gas (LPG). By 2030, it is planned that the share of energy from renewable sources in the gross final energy consumption of the transport sector will be at least 17%, which, in natural terms, equates to 830 thousand toe (**Table 4.16**). The consumption of liquid biofuels (bioethanol, biodiesel) will account for 420,000 toe, including bioethanol from food and feed crops – 398,000 toe, bioethanol from waste and residues (second generation) – 10,000 toe, biodiesel from waste and residues (second generation) – 12,000 toe. Additionally, the consumption of biomethane from waste and residues (second generation) will be 500 toe and biomethane from methanation of hydrogen and biogenic CO_2 will be 500 toe.

If we assume the **minimum biomethane consumption scenario** for replacing motor fuels in agriculture to be 1 thousand tons of CH_4 **in 2030** by the National Renewable Energy Action Plan for the period up to 2030, then the need for biomethane is **about 1.2 million m^3**. This is enough for the operation of 42 tractors of the NH T6.180 analogues with an annual load of 1,500 engine hours. The expected capital expenditure for the biomethane tractors is 7.6 million EUR.

In the National Energy and Climate Plan for the period up to 2030, the national indicative target for renewable energy sources in the **gross final energy consumption in the transport sector by**

[168] https://optiblendfuels.com/dual-fuel-engine/
[169] National Renewable Energy Action Plan for the period up to 2030 https://www.kmu.gov.ua/npas/pro-zatverdzhennia-natsionalnoho-planu-dii-z-vidnovliuvanoi-enerhetyky-na-p-a761

2030 is 17.2%[170]**. If diesel fuel in agriculture is replaced with an appropriate share of biomethane, the potential agricultural consumption will be 224 million cubic meters of biomethane in 2030.** This can be considered a maximum consumption scenario and this volume of biomethane will be enough to operate 7.8 thousand tractors similar to NH T6.180, with a total cost of about 1.4 billion EUR.

Therefore, by 2030, Ukraine requires varying biomethane volumes for different agricultural goals: 224 million m^3 to replace 17.2% of diesel fuel, and 1.2 million m^3 for the National Renewable Energy Action Plan. Complete motor fuel replacement in agriculture, however, would require approximately 1.3 bcm. Given the significant variations in the presented results, developing a comprehensive Strategy for Biomethane Production and Use in Ukraine is crucial to establishing clear and specific goals. In addition, support for agricultural producers is essential to enable the economic transition to biomethane-powered machinery, including in the form of monetization of greenhouse gas emission reductions.

[170] National Energy and Climate Plan for the period up to 2030 https://me.gov.ua/view/bb0b9ef5-ea96-4b8a-8f2f-471faf32c9df

5. Existing barriers and possible ways to overcome them

5.1 Economic barriers

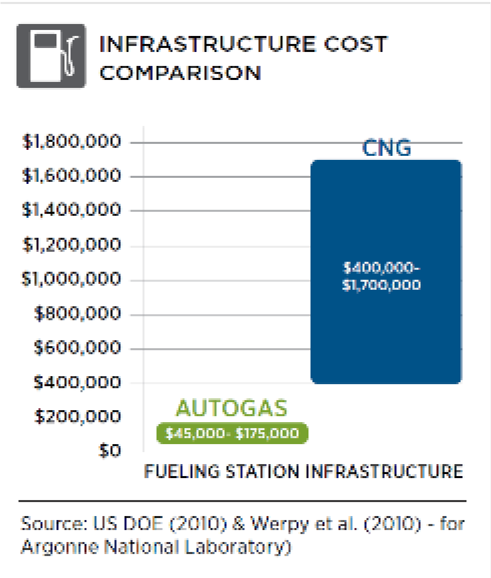
High production cost compared to fossil fuel

As shown in section 3.4, the use of biomethane as a transport fuel faces the problem that biomethane at the exit of the biomethane plant will most likely have a higher cost than natural gas. Substantial investments in the infrastructure of the biomethane plant will require significant mark-ups in order to be recovered through the sale of biomethane. In addition, the infrastructure and processes for the production and retail of bio-CNG and bio-LNG themselves require additional capital and operating costs. As a result, compressed natural gas will have a price advantage over bio-CNG, as shown in **Fig. 3.23**. One of the significant cost components in the production of biomethane is the cost of raw materials (**Fig. 3.13**). According to our rough estimate, even with zero feedstock costs, bio-CNG is unlikely to have the same price as CNG from natural gas.

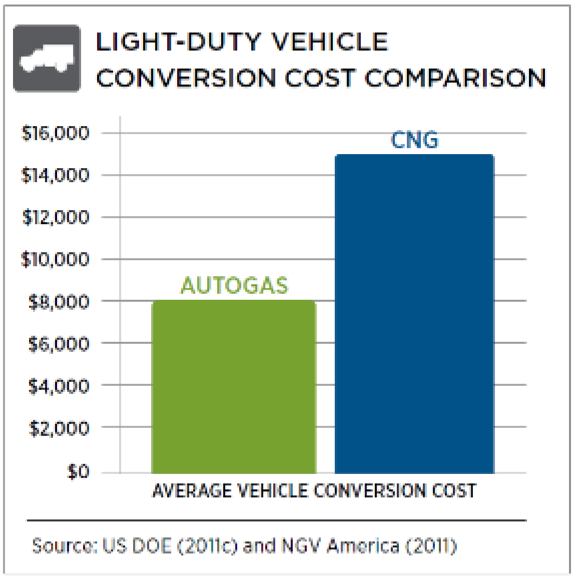
Infrastructure investment, need for refuelling and vehicles modifying

Vehicles designed to run on CNG or those converted to use CNG often come with higher initial costs. This is attributed to the specialized fuel storage tanks and fuel system modifications required for CNG use. For instance, converting a gasoline-powered vehicle to a CNG bi-fuel system can cost around $8,750[171]

It should be noted that if we compare the cost of infrastructure for using liquefied propane-butane, the infrastructure for switching to CNG will be significantly more expensive (**Fig. 5.1**)[172].



a) Infrastructure costs



b) Vehicle conversion costs

Fig. 5.1. Comparison of investments to switch to CNG comparing to switch to propane-butane

171 https://www.automotive-fleet.com/156256/the-economics-of-natural-gas-vehicles
172 https://bluestargas.com/wp-content/uploads/2022/02/Cost-Analysis-of-Natural-Gas-Vehicles-and-Fueling-Infrastructure.pdf

Other notable barriers include the initial investment cost and the complexity of vehicle conversion. The cost of converting vehicles to use CNG, including the installation of CNG systems, may be prohibitively high for some vehicle owners. The technical complexities involved in converting a vehicle's fuel system to accommodate CNG can be a deterrent, particularly for those who lack access to conversion services or expertise.

The acquisition of LNG trucks today leads also to high additional costs compared to diesel trucks[173]. Various sources estimate the additional costs at 35,000 € – 45,000 € than the costs of the comparable diesel truck (90,000 €). The costs for the maintenance, care and repair of LNG trucks are slightly higher than those of diesel trucks, 0.16 €/km for LNG truck compared to 0.14 €/km for a diesel truck (**Fig. 5.2**).

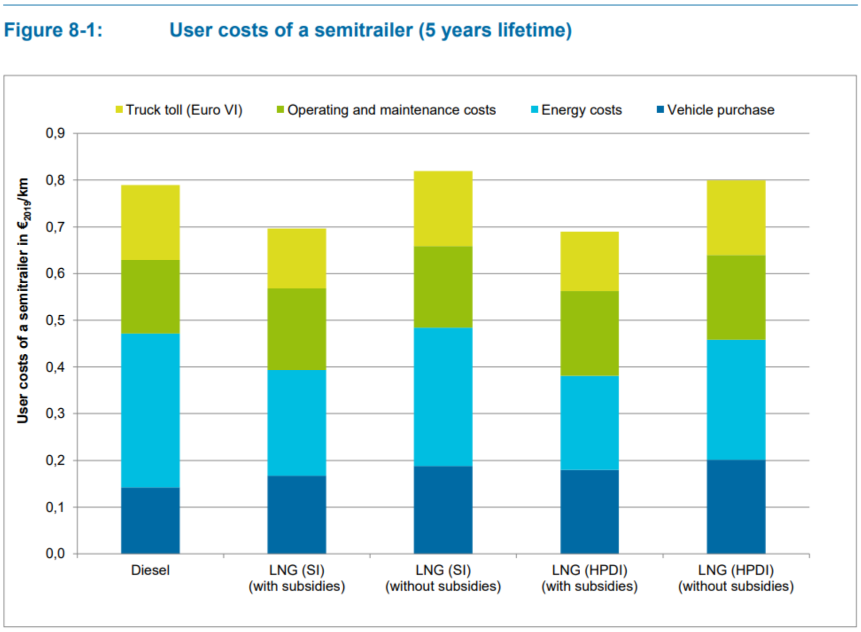


Fig. 5.2. User costs of a semitrailer (5 years lifetime)

5.2 Technological barriers

Limited refuelling infrastructure

The Driving Range is a major hurdle in the development and growth of CNG as transportation fuel[174]. Range for CNG cars 2-2.5 times less than for LNG-fuelled cars (**Fig. 5.3**). In practice, this means that to ensure fuel availability, CNG stations must be located more densely than for LNG ones.

The lack of natural gas infrastructure is the most prominent challenge, which affects 40% of vehicle owners. This suggests that the limited availability of refuelling stations is a major deterrent, making it difficult for owners to conveniently access CNG. The scarcity of these stations likely adds logistical challenges, such as the need to travel long distances to refuel, which makes natural

[173] https://www.iea-amf.org/app/webroot/files/file/Country_Annex_Reports_2016_pdf/Annex_49.pdf
[174] https://www.sciencedirect.com/science/article/abs/pii/S1364032115006255

gas less attractive compared to traditional fuels like gasoline and diesel, which have a well-established refuelling infrastructure[175].

For heavy duty vehicles moving through countryside, the conversion to CNG presents several challenges, including the lack of a rigorous refuelling infrastructure, higher vehicle capital costs and limited engine offerings. Until a competitive natural gas refuelling infrastructure evolves, this alternative fuel is problematic for long haul, irregular route trucking operations.

Additionally, any accident to the natural gas transmission pipeline can cut off the fuel supply of the whole city or of a specific region.

Manufacturer	Iveco	Iveco	Iveco
Model	Daily	Eurocargo	S-Way
Range	350+1500 km (CNG+Petrol)	400 km (CNG)	600 km (CNG) 1600 km (LNG)
Effect	136 hp (350 Nm)	204 hp (750 Nm)	340-460 hp (1500-2000 Nm)
Max load	2700 kg	9-16 Tons	18-32 Tons
No of passengers	2	1-2	1-2

Manufacturer	Scania	Scania	Scania
Model	G-Series	L-Series	P-Series
Range	800 km (CNG) 1600 km (LNG)	800 km (CNG) 1600 km (LNG)	800 km (CNG) 1600 km (LNG)
Effect	280-460 hp (1350-2300 Nm)	280-410 hp (1350-2000 Nm)	280-340 hp (1350-1600 Nm)
Max load	16-74 Tons	16-32 Tons	16-32 Tons
No of passengers	1-2	1-2	1-2

Manufacturer	Scania	Volvo	Volvo
Model	R-Series	Fe CNG	Fm LNG
Range	800 km (CNG) 1600 km (LNG)	400 km (CNG)	1000 km (LNG)
Effect	280-460 hp (1350-2300 Nm)	320 hp (1350 Nm)	420-500 hp (2100-2500 Nm)
Max load	16-74 Tons	18-32 Tons	18-74 Tons
No of passengers	1-2	2	1-2

Fig. 5.3. Examples of CNG and LNG-fuelled heavy duty vehicles[176].

"Chicken-and-egg" problem

The inadequate number of CNG refuelling stations is a barrier to the embracement of natural gas fuelled vehicles by consumers. Similarly, the lesser number of NGVs required CNG refuelling stations makes establishment and operation of a CNG station uneconomical. It is believed that for the sustainable use of CNG as transportation fuel two conditions must be addressed. First, for the CNG stations to be profitable there should be at least 1000 natural gas vehicle per CNG refuelling station. Second, to minimize the refuelling time and facilitate the motorists, the minimum range of CNG refuelling stations should be at least 10–20% of the number of gasoline/diesel stations.

Storage and transport issues

Storage and transport issues are important components that also underlie problems with insufficient transport infrastructure. On volumetric basis, one litre of LNG roughly corresponds to 1.26 l of gasoline or 1.44 l of diesel (**Fig. 5.4**). Because of this lower energy density of natural gas as compared to gasoline or diesel, NG takes 3–4.5 times more space for storage than gasoline or diesel which consequently reduced the vehicle range.

[175] https://dx.doi.org/10.4314/jpds.v16i2.13
[176] https://biofuelregion.se/wp-content/uploads/2023/05/Best-Ace-State-of-play-FINAL-VERSION.pdf

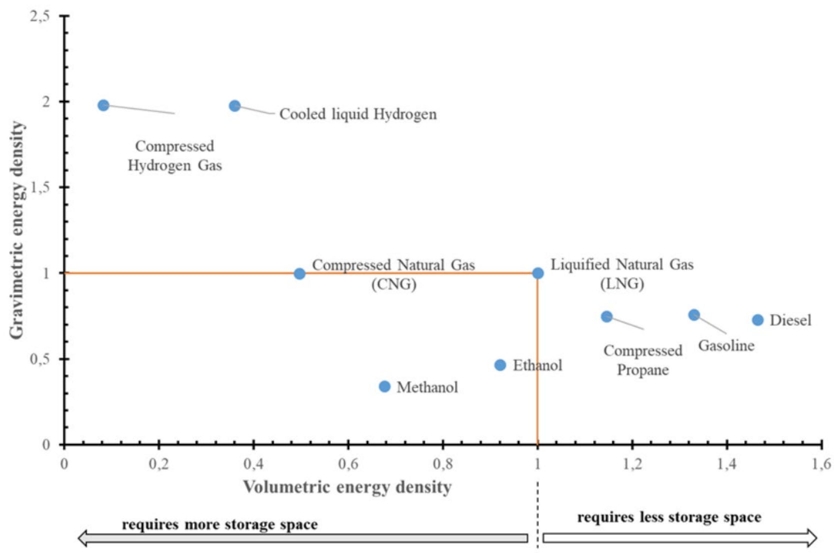


Fig. 5.4. Energy density of transport fuels[177]

LNG is more energy dense than CNG, i.e. LNG is more suited for vehicles used at longer range. Long-haulage vehicles must carry a large amount of fuel, which they do not get from CNG. Generally, one litre of diesel corresponds of 5 litres of CNG at 200 bar, and to 1.7 litre of LNG (**Fig. 5.5**).

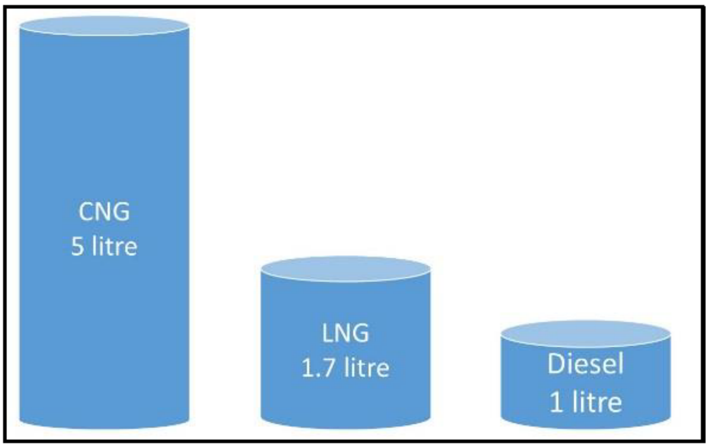


Fig. 5.5. Comparison of volume that contains the same amount of energy, between CNG, LNG and diesel[178]

The result for vehicles using natural gas, especially light duty ones is the loss of cargo space. CNG cylinders are large and occupy a lot of storage space and generally have to be placed in the boot of the car. Owing to this it significantly decreases the cargo space by almost 50% as compared to conventional fuel vehicle. For the dedicated CNG vehicle this deficiency is fixed by equipping with 2 to 3 cylinder all under the vehicle so no luggage space is lost.

Refuelling time

Refuelling time for natural gas fuelled vehicles is longer than either diesel or gasoline vehicle and sometimes user have to wait for hours in long queues to get their vehicle refuelled due to

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177 https://www.marcogaz.org/wp-content/uploads/2021/06/LNG-as-transportation-fuel.pdf
178 https://www.diva-portal.org/smash/get/diva2:844798/FULLTEXT02.pdf

insufficient number of refuelling stations. Refuelling is considered to be the ‘least safe’ moment of its use.

Safety risks

The next major issue is related to safety risks, which concern 22% of vehicle owners. This reflects apprehension about the perceived dangers associated with using CNG, such as the risk of gas leaks or explosions. While CNG is generally considered safe, the lack of widespread use and misinformation may contribute to these concerns. The fear of safety risks could prevent more vehicle owners from converting to or adopting natural gas, especially if these perceptions are not adequately addressed through public awareness campaigns or improved safety measures.

Vehicle compatibility

The age and condition of vehicles present a significant challenge to CNG adoption. Older vehicles may not be technically or economically viable for conversion to CNG, as retrofitting can be both complex and costly.

LNG: boil-of gas problem

Evaporation losses in the LNG supply chain are one of the key factors for LNG safety, technical and economic assessment. LNG is stored and transported in tanks as a cryogenic liquid, i.e. as a liquid at a temperature below its boiling point at near atmospheric pressure. Due to heat entering the cryogenic tank during storage and transportation, a part of the LNG in the tank continuously evaporates creating a gas called Boil-Off Gas (BOG), which changes the quality of LNG over time[179].

When boil-off venting does take place, approximately 2 % to 4 % of the tank’s fuel mass is released per day. The daily boil-off venting emissions in 2.6 % of the initial amount of LNG in the tank. It leads to the contribution of boil-off venting emissions relative to the vehicle’s lifetime CO_2 tailpipe emissions. If 1 to 5 venting events occur per year, boil-off emissions would represent 0.4% to 1.8% of the lifetime tailpipe CO_2 emissions.

Depending on the type of tank and the application different BOG handling methods are used alone or in combinations[180]:

- BOG containment in pressurized Type C tanks;
- BOG "flaring" in Gas Combustion Units (GCU);
- BOG as a fuel for ship propulsion;
- BOG as a fuel for auxiliary engines;
- BOG reliquification.

5.3. Regulatory and policy barriers for biomethane usage in the transport sector in Ukraine

The National Energy and Climate Plan for 2030[181] sets a range of targets across various dimensions, including decarbonization, energy efficiency, and energy security, like at least 27%

[179] https://www.researchgate.net/publication/269748499_Problem_of_Boil_-_off_in_LNG_Supply_Chain
[180] https://www.politesi.polimi.it/retrieve/a81cb05b-9569-616b-e053-1605fe0a889a/thesis_Battistelli_v05.pdf
[181] https://www.kmu.gov.ua/en/news/ukraina-zatverdyla-natsionalnyi-plan-z-enerhetyky-ta-klimatu-v-den-pochatku-peremovyn-pro-vstup-do-ies

RES of total final energy consumption by 2030. Additionally, indicative RES targets for gross final energy consumption in the transport sector with a 14% share by 2030, highlighting the need for effective policies to support the integration of biomethane as a sustainable fuel alternative.

However, one of the key barriers to the development of biomethane in the transport sector in Ukraine is the **absence of approved long-term strategic goals for the bioenergy and biomethane sector**. Ukraine lacks a legally binding strategy and roadmap for biomethane production, consumption, and integration into the energy systems. This uncertainty discourages investment, as businesses and financial institutions require clear policy commitments to justify long-term investments in biomethane production facilities and refuelling infrastructure.

A significant barrier to the development of biomethane in Ukraine's transport sector is **the absence of a fundamental law specifically regulating its production and use in transport**. While general provisions for biomethane production exist, there is no clear legal framework defining biomethane as a transport fuel, setting quality and safety standards, or establishing mechanisms for its distribution. This legal vacuum creates uncertainty for producers and fuel suppliers, limiting investment and infrastructure development.

Additionally, Ukraine **lacks national targets and commitments for biomethane use in transport**, unlike EU countries that set binding quotas for renewable energy in fuel consumption. Without defined goals, there is no policy driver to ensure biomethane adoption, making it difficult to integrate it into the transport energy mix. This absence of strategic direction weakens market confidence and slows down the development of biomethane production.

A major barrier to the adoption of biomethane in Ukraine's transport sector is **the absence of established technical requirements for its use as a motor fuel**. There are no clear national standards regulating the composition, quality parameters, or safety criteria for biomethane in transport applications. This creates uncertainty for fuel producers and infrastructure developers, as there are no officially approved specifications for biomethane's compatibility with engines and refuelling systems.

A significant barrier to the development of biomethane in Ukraine's transport sector is the declining consumption of natural gas as a motor fuel. The number of compressed natural gas refuelling stations **has been steadily decreasing**, reducing accessibility for vehicles that could potentially switch to biomethane. At the same time, there are **no liquefied natural gas refuelling stations in Ukraine**, which limits the possibility of using bio-LNG for heavy-duty and long-haul transport. This shrinking infrastructure discourages investment in gas-powered transport solutions and creates additional challenges for integrating biomethane into the market.

A significant regulatory barrier to the development of the bioenergy sector in Ukraine is the requirement to pay CO_2 emissions tax for biomass and biofuel-based energy production. Unlike fossil fuels, which contribute to net carbon emissions, biomass, biogas, bioethanol, and biomethane are considered renewable energy sources with a closed carbon cycle. However, in Ukraine, boiler houses, combined heat and power plants, and thermal power plants using biomass or biogas, as well as **facilities producing bioethanol and biomethane, are subject to CO_2 taxation**. This creates an additional financial burden on biomethane producers, reducing the economic viability of these renewable alternatives compared to fossil fuels. The taxation policy contradicts global and EU practices, where bioenergy is generally exempt from CO_2 emission fees due to its role in reducing greenhouse gas emissions.

A major barrier to the development of biomethane in Ukraine's transport sector is the **absence of support schemes, financial and regulatory incentives to support its production, distribution, and use**. Unlike in the EU, where biomethane benefits from tax exemptions, investment grants, blending mandates, and GHG reduction quotas, Ukraine lacks targeted mechanisms to make biomethane competitive with fossil fuels.

The only example is a state support program for investment projects with significant investments, benefiting biomethane projects[182]. Key incentives include five-year corporate income tax exemptions, VAT and customs duty exemptions on new equipment, and government-funded infrastructure support for roads and utilities. Investors can also access simplified land leasing with preferential purchase rights and cost reimbursements for grid and transport connections. To qualify, a project must invest at least €12 million, create 10–50 jobs, and be completed within five years.

Another example is the regulation for biogas use in transport in Ukraine[183]. In cities with a population exceeding 250,000, at least 25% of public buses must be either electric or powered by compressed natural gas (CNG), liquefied natural gas (LNG), or biogas by January 1, 2030. This share must increase to 50% by January 1, 2033, unless local governments decide on different proportions or timelines. Local authorities have the right to adjust the required share by up to 50% and modify the deadlines by no more than two years. Starting from January 1, 2036, only electric buses, biogas-powered buses, or hydrogen fuel cell buses will be allowed for public transport operations in cities of district and regional significance, unless local governments decide otherwise within a two-year adjustment period. Additionally, from January 1, 2028, public transport procurement in cities with over 250,000 residents must ensure that at least 50% of newly purchased buses are electric or run on CNG, LNG, or biogas. By January 1, 2030, the procurement of diesel or gasoline-powered buses will be completely prohibited, except for those using CNG, LNG, biogas, or hydrogen fuel cells, with local governments able to modify quotas or deadlines within specified limits. For all other settlements, the purchase of internal combustion engine buses will be prohibited from January 1, 2030, except for those operating on CNG, LNG, or biogas, unless local authorities set a different timeline. However, due to martial law, the implementation of these requirements may be extended.

Lack of a domestic emissions trading system. A significant challenge for the widespread adoption of biomethane in the transport sector is the absence of a robust domestic emissions trading system (ETS). Without an internal ETS, there is no clear mechanism to price carbon emissions, which hinders the economic viability of low-carbon alternatives like biomethane. This gap in policy creates an uneven playing field, where the environmental cost of conventional fuels, such as gasoline and diesel, is not fully internalized. As a result, biomethane, despite its potential to significantly reduce greenhouse gas emissions, faces market disadvantages. Furthermore, the lack of an ETS reduces the incentive for companies to invest in sustainable technologies and infrastructure for biomethane production, distribution, and use.

[182] https://ukraineinvest.gov.ua/en/incentives/investment-projects-with-significant-investments/
[183] https://ips.ligazakon.net/document/T232956?an=87

6. General recommendations

To overcome the regulatory and policy barriers hindering the growth of biomethane usage in the transport sector, it is crucial to adopt a long-term, strategic approach. One of the most effective ways to address this issue is by:

Developing a Bioenergy/Biomethane Strategy and Roadmap till 2050. This would outline clear goals, milestones, and timelines for the development and integration of bioenergy sources, including biomethane, into the Ukrainian energy and transport sectors. By laying out specific, measurable targets for biomethane production, distribution, and use, stakeholders (government, private sector, and consumers) will have a clear framework to guide their investments and actions. A long-term vision will also help attract investments by demonstrating a commitment to the growth of bioenergy as a sustainable and reliable energy source. If Ukraine updates its Energy Strategy to include concrete bioenergy targets and initiatives, biomethane could be directly supported as a key element of the national energy mix. By setting clear goals for the transport sector's decarbonization and increasing the share of renewable fuels, the strategy could provide the policy stability needed to promote biomethane adoption. This inclusion would also ensure that biomethane is considered alongside other renewable energy sources, ensuring it receives the necessary support and investment in terms of both infrastructure and incentives.

Development of basic law on biomethane use as motor fuel. A comprehensive legal framework is needed to support the use of biomethane as an alternative motor fuel. This draft law should address the regulatory, financial, and technical aspects necessary to promote biomethane as a viable fuel for various types of vehicles, particularly public transport and agricultural machinery. The law could include provisions on incentives, funding, and technical standards for the adoption of biomethane, helping to ensure widespread uptake.

Setting of biomethane consumption targets. Specific biomethane consumption goals are essential to provide a clear direction for future development. Setting a target of 5-10% of natural gas consumption for transport coming from biomethane by 2030 would provide the framework necessary to guide production and market penetration. This target would also signal to stakeholders the government's commitment to advancing bioenergy solutions and incentivize investments in biomethane production and infrastructure.

Set targets for the number of the gas refuelling stations. To facilitate the widespread adoption of biomethane in transport, the government should set specific targets for the expansion of refuelling infrastructure, particularly gas stations that can accommodate biomethane (CNG and LNG). These stations would need to be built across key regions to provide reliable access to biomethane fuel for vehicles. Incentives for private sector investment and public-private partnerships should be explored to develop this infrastructure. In addition to establishing targets, there should be support for the development of gas refuelling stations, both for compressed natural gas and liquefied natural gas. This could include financial incentives for station construction, subsidies for equipment, and grants for operators who choose to offer biomethane as a fuel option.

Establishment of technical standards for biomethane in CNG and LNG applications. Development of a set of national technical regulations defining the quality parameters, safety requirements, and compatibility of biomethane for use in compressed natural gas and liquefied natural gas applications. The technical requirements should cover aspects such as gas composition, pressure levels, and impurities to ensure that biomethane can be safely used in existing CNG/LNG refuelling stations and vehicle engines without modifications. Aligning Ukraine's biomethane standards with European and international regulations (such as EN 16723-2 for biomethane in transport) will facilitate the integration of biomethane into cross-border markets and ensure compliance with future requirements for exports and certification.

Amendments to the Tax Code. The amendments suggest introducing a zero-rate environmental tax for CO_2 emissions from installations burning biomass fuels. This is an important policy step to support the development of bioenergy, particularly biomethane production, as it reduces the financial burden on producers of biofuels, including biomethane. It is crucial to expand the scope of this tax exemption by including installations that produce bioethanol and biomethane in the list of installations exempt from the environmental tax. By doing so, Ukraine would incentivize the development of these renewable energy sources, making their production more economically viable and competitive compared to fossil fuel-based options.

To stimulate the adoption of biomethane as a sustainable fuel alternative in the transport sector, it is recommended that the government introduce VAT and import duty exemptions for vehicles powered by biomethane, similar to the incentives currently provided for electric vehicles. This policy would create a financial incentive for consumers and businesses to invest in biomethane-powered transport, making it more competitive with conventional fossil fuel vehicles.

Conclusion

The development of biomethane as a transport fuel in Ukraine presents a significant opportunity to reduce GHG emissions, enhance energy security, and support the transition toward a more sustainable energy sector. However, several regulatory and policy barriers must be addressed to unlock its full potential. The general recommendations outlined above provide a basic framework for overcoming these challenges and fostering the growth of biomethane usage in transportation. By implementing these recommendations, Ukraine can establish a strong foundation for biomethane adoption in the transport sector.