FlexSNG

# Deliverable D6.3

# Summary report of biomethane utilization pathways

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## Abbreviations and acronyms

| | |
|---|---|
| AD | Anaerobic digestion |
| bcm | billion cubic meter |
| CNG | Compressed Natural Gas |
| EC | European Commission |
| HHV | Higher heating Value |
| LBG | Liquified Biogas; Liquified Biomethane; Bio-LNG |
| LHV | Lower Heating value |
| LNG | Liquified Natural Gas |
| n.a. | not available |
| NG | Natural Gas |
| RE | Renewable Electricity |
| RNG | Renewable Natural Gas |
| SNG | Synthetic Natural Gas, Sustainable Natural Gas |
| TEA | Techno-Economic Assessment |
| WI | Wobbe-Index |

# 1 Executive summary

This deliverable D6.3 “Summary report of biomethane utilization pathways” deals with the valorization of the main FlexSNG product biomethane. In its first part, the regulatory constraints regarding biomethane feeding into the gas grid, its use as transportation fuel as well as sustainability criteria according to REDII are presented. In the second part, an overview about the current use and market environment for biomethane is provided. The main goal of D6.3 is to compile and characterize the different opportunities for distribution and final use of biomethane from FlexSNG. This work prepares the ground for the subsequent executive summary deliverable D6.4 about all bioenergy carriers, the techno-economic assessment in WP7 as well the work on the different case studies in WP8.

In most European countries, biomethane substitute is already produced from anaerobic digestion. Therefore, legislation, gas specifications and standards for injection into the grid and for transport fuel use are already established. The European harmonization of national standards (EN-16273 and EN-16723-1) for gas quality requirements is ongoing, but not yet finished in all details. Therefore, national standards keep their relevance as well. For fuel use, EN-16723-2 determines the minimum quality requirements, and the REDII the sustainability criteria.

Besides the use for transport, biomethane replaces natural gas for power and heat in different applications and sectors. For which end use depends on the overall role of natural gas in the energy system, the existing gas infrastructure and the incentives provided for biomethane. All of these criteria are very diverse between the different European countries, and Canada as well. Therefore, the current use of biomethane varies in different countries, e.g. for electricity production in Germany, for heat in UK and Canada and as CNG /LNG in Italy and Sweden.

The use of biomethane will increase in the whole transport sector, at least for the next decades, how long is depending on the future availability of green hydrogen. So, the long-term perspective is limited to maritime and heavy-duty segment.

## 2 Introduction

This deliverable D6.3 deals with the distribution and utilization options of the gaseous product from the FlexSNG process, biomethane. The main goal of D6.3 is to gather and provide the required data for the TEA in WP7 and the case study investigations in WP8.

Biomethane is part of the Green gas family, which comprise beside Renewable Natural Gas (RNG) green hydrogen as well. RNG is either from biomass or wastes through anaerobic digestion or gasification, or from CO2 methanation to methane with green hydrogen from electrolysis (see Figure 1). Synonymously used are often the terms Synthetic Natural Gas (SNG), biomethane if it stems from biomass and e-methane, emphasizing the electrolytic hydrogen for its production. For latter one, fossil CO2 can be used as well. Biogas again is chemically different and used for the mixture of methane and CO2 from AD, which can easily be upgraded to biomethane through CO2 removal. Finally, syngas is the CO/H2 rich gas from gasification which can be converted to (bio-)methane via methanation like in the FlexSNG process. Methane in compressed form is referred as compressed natural gas CNG and liquefied as liquefied natural gas LNG, respectively bio-CNG and bio-LNG for biomethane. Synonymously used are compressed biomethane CBM and liquefied Biomethane LBM.

Biomethane can directly substitute natural gas; alternatively, it can be blended with it. Therefore, distribution and use are the same than for natural gas.

Biomethane injection into an already existing on-site gas grid is obviously the simplest and cheapest option. The distribution as bio-CNG or bio-LNG via trucks or vessels requires additional efforts for liquefaction or compression. However, in the case of a missing gas grid access and no nearby gas consumers, both are alternative solutions. Obviously, the biomethane distribution for a FlexSNG plant depends on the local existing gas infrastructure.

Biomethane can be used for electricity or heat production (domestic, district or industrial heat) as well as transport fuel in form of bio-CNG and bio-LNG. Latter ones enable as well gas use in remote areas with no gas grid connection.

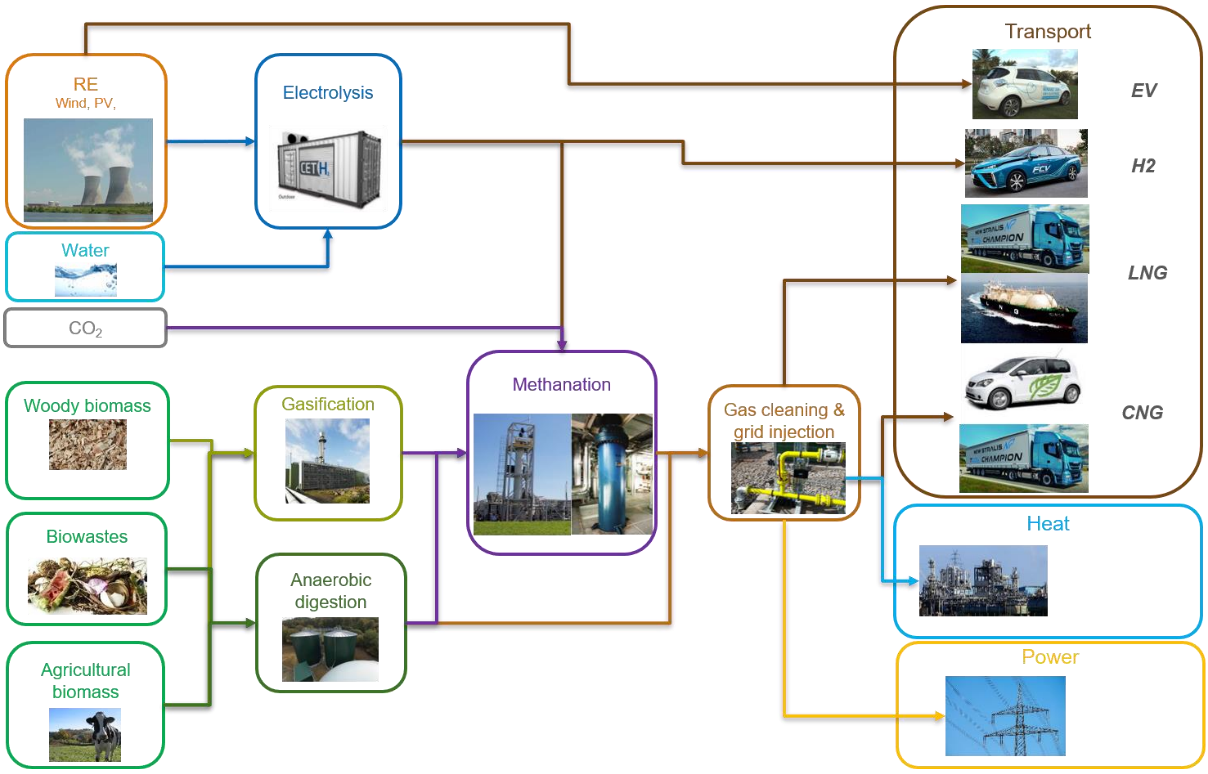


*Figure 1. Overview of different RNG production routes.*

Biomethane from gasification is not commercially available at the moment. The only commercial-scale production site in Gothenburg was decommissioned after more than 12.000 hr of operation in 2018 (Larsson, 2018). The price gap between biomethane to natural gas and biogas was too high for economic competitiveness. However, biomethane from AD with subsequent upgrading to biomethane is commercially available since more than 20 years. In 2021, 200 TWh of biogas (5% of EU gas consumption) was produced in Europe, of which 31 TWh was upgraded to pure biomethane. So, many experiences regarding technical aspects as well as markets for distribution and use exists already, e.g. grid injection specifications or use as transport fuel.

Biomethane was significantly more expensive than natural gas in the past, despite increasing CO2 certificate prices. In order to close this price gap, various funding schemes for biomethane promotion were set up, e.g. investment supports, feed-in tariffs for injected biomethane into the gas grid, for electricity production or biofuel quota in the transport sector. As well, some gas consumers have shown willingness to accept higher prices for biomethane to green their products on a voluntary base.

The situation changed drastically in 2022. The European gas markets were facing huge disruptive changes regarding supply security as well a sharp rise in gas prices. Even if it is unclear whether the gas prices will stay at the very high 2022 level, the replacement of Russian pipeline gas imports through LNG from other countries will likely result in higher European gas prices in the mid-to long-term, but higher gas prices close or at least reduce the price gap. Highly uncertain are the effect on the gas demand and the existing funding schemes.

Subsequent, an overview about some key aspects for placing biomethane from FlexSNG in the gas markets are provided.

# 3 Structure of Deliverable 6.3

The deliverable D6.3 is split into two main parts, one for technical and regulatory constraints and one on economic aspects for biomethane from FlexSNG process. Due to the missing date and experience for biomethane from gasification, the literature relies on the experiences and data for biomethane from AD. The subsequent chapters are mainly based on literature review and some former projects.

The first part is dealing with the regulatory constraints for biomethane distribution and use, which includes gas grid feed-in quality s, fuel as well as sustainability standards. The harmonization of standards on the European level is still ongoing and not yet finished, therefore, national standards are compiled as well.

The second part is dedicated to the economic situation for biomethane. This includes the past and future prices for natural and renewable gases, the additional costs for compression and liquefaction of biomethane as a very short characterization of the different national gas infrastructures, markets and funding schemes.

# 4 Regulatory constraints

Even if RNGs are low-carbon substitutes for natural gas, these gases are not fully identical with natural gas. The gas composition, amount and types of impurities and accompanying components are more or less different, depending on the origin of the natural gas, the different RNG production as well as upgrading technologies.

In order to avoid damages to the gas infrastructure and installations through fluctuating or different gas compositions, technical standards were set up decades ago. These standards are usually managed by national authorities for each country; and so, each country has slightly different standards. In order to replace natural gas within the existing gas infrastructure, biomethane must meet these quality requirements.

Even if RNG are quite new, and extensive and long-term experiences is still missing, their relevance increases continuously. Therefore, the current gas standards are currently adapted for the renewable gas integration, not least to make the gas grids ready for hydrogen injection. The broad variety, the different availabilities and timelines for RNGs, the historic grown gas infrastructures and market background complicate these efforts. In parallel, the harmonization of gas standards to create a common European gas market has already started, even worsen the complexity of the process.

In general, biomethane has to fulfil the gas quality requirement of the gas network operator at the injection point at the distribution or transmission grid. In the case of fuel use for transport, the fuel requirements of the European standard have to respected as well.

An overview about the key gas characteristics is given in 0, which have also to be considered for the decision of the final FlexSNG gas cleaning, upgrading and conditioning scheme. Subsequent the European and national gas standards are compiled, as well as the sustainability criteria for biofuel which have to be considered.

## 4.1 Key characteristics for gases

The most crucial parameter is the **energy content** of a fuel gas, based on the HHV or LHV. However, for the replacement of a gas, like natural gas by RNG, the Wobbe-Index (WI) is the more appropriate characteristic. The WI describes the interchangeability of fuel gases by considering the fuel density as well; so, two gases with the same WI may have different volume and mass flows, but the same energy content, which is crucial for an efficient use of different gases in the same installation.

Another important parameter is the **sulfur content**. Sulfur components like H2S are highly toxic, corrosive and poisoning most catalysts: The sulfur after combustion is released as SOx in the exhaust gases, which is an environmental danger. Therefore, strict limits regarding the sulfur content of fuels apply. However, natural gas is a colorless, explosive light gas; so, to detect leakages well before explosion limits are reached, natural gas is odorized with special, very often sulfur containing chemicals. For the FlexSNG process, sulfur is as well a danger as catalyst poison; so, the FlexSNG process comprise a desulfurization step before the methanation unit. The responsibility for the required odorization before placing on the market lies either by the plant or by the gas distributor, depending on the local or national legislation.

The **water** amount allowed in gases depends on the distribution and final end use. The formation of liquid water causes severe risks like corrosion or blockages with subsequent pressure increase; therefore, strict limits have to be fulfilled, depending on the pressure and temperature levels of grids, underground gas storages, tanks or fueling stations for CNG or LNG. Water is one by-product of the methanation process; so, for FlexSNG water removal to the required levels is a mandatory step.

Also, an important parameter is the **oxygen** content of gas, due to its corrosive and highly reactive character. Furthermore, gases should be as clean as possible from other **hydrocarbons, halogenated hydrocarbons** and other **liquids** like oil or solids like dust.

## 4.2 Technical standards for grid injection and transport fuel

Although the final biomethane quality of the FlexSNG biomethane is still unclear, its gas quality for distribution and use as well as its sustainability requirements have to be considered.

On a European level, three EN standards determine the minimum required gas quality of biomethane for its injection to the grid as well as its use as fuel in the transport sector:

EN 16276:2015 +A1:2018 describes the gas quality for high calorific fossil gases („H-gas “) (CEN, Gas infrastructure - Quality of gas - Group H, 2018)

EN 16723-1 („Natural gas and biomethane for use in transport and biomethane for injection in the natural gas network – Part 1: Specifications for biomethane for injection in the natural gas network “) (CEN, Natural gas and biomethane for use in transport and biomethane for injection in the natural gas network - Part 1: Specifications for biomethane for injection in the natural gas network, 2016)

EN 16723-2 („Natural gas and biomethane for use in transport and biomethane for injection in the natural gas network – Part 2: Automotive fuels specification ") describes the standard requirements of biomethane for grid injection and automotive fuel use (CEN, Natural gas and biomethane for use in transport and biomethane for injection in the natural gas network – Part 2: Automotive fuels specification, 2017)

The respective parameters for each standard are summarized in Table 1.

*Table 1. European specifications for biomethane.*

| | **EN 16276** | **EN 16723-1** | **16723-2** |
|---|---|---|---|
| Relative density | 0,55-0,75 | | |
| Total S [mg/Nm$^3$] | <20 | | <30 |
| H2S & COS [mg/Nm$^3$] | <5 | | <5 |
| Mercaptans-S [mg/Nm$^3$] | <6 | | |
| O2 [mol-%] | <0,001 (or 1) | | 1 |
| CO2 [mol-%] | <2,5 (or 4) | | |
| HC dew point (≤ 70 bar) | -2°C | | -2°C |
| H2O dew point (≤ 70 bar) | -8 | | -10/-20/-30°C |
| Methane number | >65 | | >65 |
| Total Silicates [mg Si/m$^3$] | | <0,3 - 1 | <0,3 |
| CO [mol%] | | 0,1 | |
| NH3 [mg/Nm$^3$] | | <10 | |
| Amines [mg/Nm$^3$] | | <10 | <10 |
| Oil | | minimum | |
| Dust | | minimum | < 10 mg/l (for LNG) |
| Chlorinated HC | | minimum | |
| Fluorinated HC | | minimum | |
| H2 [mol-%] | | | 2 |

There are differences for total sulphur, oxygen and silicates amounts, depending on the intended use. For grid injection, a very low oxygen content is required to avoid corrosion effects within connected underground gas storages. For transport fuel use, oxygen is less problematic; however, silicates can cause here severe trouble in internal combustion engines. The sulphur content again is highly important for all gas application as well to avoid costly damages on the equipment. No statement on the range of the energy content or the WI is provided in the three standards, only a minimum energy content is provided through the methane number.

However, their national gas standards are still valid for most countries, with additional threshold ranges and often stricter restrictions than the European EN standards. The different national standards for gas composition in Denmark, Finland, France, Germany, Italy, Sweden and UK are shown in Appendix 8, as well as for Canada. For Sweden and Greece, no requirements for the gas composition exist beside the above European EN standards; however, Sweden has developed a standard for biomethane as a fuel.

There are two characteristics with major differences between the countries; the total sulphur content and the energy content. The total accepted sulfur content in Italy is the highest, but also between the other countries the maximum tolerated sulfur concentration differs. The energy content of natural gas differs not least due to its origin, reflected in the national standards. The WI varies between 38 MJ/Nm$^3$ for L-gas up to 57 MJ/Nm$^3$.

In Canada, the situation is less restricted; so far, biomethane quality requirements for grid injection are implemented only at the provincial level in Quebec with the standard BNQ 3672-100/2012. Grid injection quality standards for RNG depend on the gas supplier at the grid connection point. Besides energy content, only the major accompanying components are limited, CO2 O2 and N2.

Finally, in most European countries bilateral agreements with the local gas grid providers are possible as well, considering the local constraints and circumstances as well, e.g. connection to high-pressure and storage-connected transmission grid.

## 4.3 Sustainability of biomethane and RED II

Besides the above technical standards, the sustainability characteristics of biomethane have to be considered as well. The European regulation on biofuels sustainability is based on the revised version of the "EU Directive on the Promotion of the Use of Energy from Renewable Sources of 11 December 2018" (RED II) as the key tool for Renewables in the EU, and so the use of biomass-based fuels as well (EU, 2018). RED II provides overall renewable energy goal of 32% for the final energy consumption in the EU, separate goals for some sectors, e.g. a share of renewable energies in transport of at least 14% in 2030, sustainability criteria for biofuels and the introduction of guarantees of origin for renewable gases. However, the Fuel Quality Directive is still valid setting specific quotas for transport sector.

For biomethane, the specific GHG emissions savings that need to be achieved compared to fossil fuels are determined in REDII, as well which substrates are considered as sustainable and eligible for biofuel production. Different thresholds for minimum GHG reduction of transport, heat and electricity are set in REDII.

*Table 2. Minimum GHG reduction targets for biofuels in different sectors (Liebetrau, 2021).*

| | Transport | Electricity & Heat | Electricity only |
|---|---|---|---|
| GHG savings required | -65% | -70%<br>(-80% from 2025%) | -70%<br>(-80% from 2025%) |
| Fossil benchmark | 94 g $CO_{2eq}$/MJ | 80 g $CO_{2eq}$/MJ | 183 g $CO_{2eq}$/MJ |
| Max. GHG allowed | 33 g $CO_{2eq}$/MJ | 14 g $CO_{2eq}$/MJ [1] | Technology dependent |

[1] conversion efficiency 90% field to wheel (100% field-to-tank for transport)

However, the RED II let each EU member state decide how to achieve the targets on GHG reduction in the transport sector. Therefore, each EU country can introduce additional sustainability criteria and quotas; so, a look on the national legislative is still mandatory.

An additional instrument introduced by REDII is the Guarantees of Origin (GoO) for renewable gases. GoOs are tradeable certificates to prove final customers the renewable origin of the gaseous fuel, independently from the physical fuel flow. One idea behind is to develop and establish a common European standardized market for biomethane and other RNG. The implementation of national GoO registries is obligatory for EU member states; however, it is a complex and time-consuming process, e.g. due to the harmonization with existing sustainability proofing systems on the national level (Swedish Gas Association, 2021). So far, GoO registries are not implemented in all EU-27 countries; Denmark, France, Finland, Germany and UK are the ones from FlexSNG countries.

Recently, more ambitious EU climate goals were announced, first in the Green Deal, later on through Fit for 55 and REPowerEU. Therefore, an adaption and update of the REDII to accelerate RE is required and ongoing. The finalizing of the revised REDII ("REDIII") is planned for the 1st quarter of 2023 (EC, 2023), and so its impact on biomethane from FlexSNG cannot be considered in this deliverable D6.3. However, the topics discussed intensively during the REDIII consultation process seem negative impacts unlikely, as wastes and residues are the addressed feedstock for FlexSNG. On the contrary, clarifying open points about renewable gases could accelerate market development and growth for biomethane.

# 5 Use of biomethane

Biomethane replaces natural gas, but costs and sustainability distinguish for both. As well, biomethane from domestic resources reduces dependence on imported natural gas. As biomethane is not the only substitute for natural gas, alternative energy carriers like hydrogen and electricity have to considered as well. All of these aspects determine the price and so the markets for biomethane finally, but make the prospective view very complex.

As biomethane is already produced through anaerobic digestion, a look on the current biomethane and natural gas market developments deliver some general insights about the future.

## 5.1 General view on the gas market

The use of biomethane market is highly linked with the natural gas market and infrastructure. In 2022, natural gas markets are subjected to high uncertainties due to shortened supply, resulting in very high price fluctuations.

To overcome the shortened gas supply from Russia, the European Commission published the REPowerEU plan which targets among other measurements a ten-fold increase in domestic biomethane production; from 3 bcm today to 35 bcm by 2030 (EC, 22). Besides the envisaged upgrading of biogas to additional 17 bcm biomethane from existing biogas plants, new plants, hydrogen from renewable electricity as well as biomethane from gasification are considered to contribute to this target. The potential of biomethane from gasification is estimated by 3 bcm for 2030 and 60 bcm for 2050 (Guidehouse, 2022),

Furthermore, the replacement of Russian pipeline gas with LNG results very likely in higher European gas prices. Not only in 2022, but also in the medium to long term due to higher production and transport costs for LNG imports. The more expensive LNG will likely become price-setting for natural gas in Europe with increasing shares. On the other hand, higher gas prices will likely lower the demand through reduced consumption and fuel switch, which may have again a dampening effect on the prices.

In Table 3, past, current and future (assumed) prices for NG, biomethane and green H2 are compiled (as production costs for biomethane from the FlexSNG process cannot yet be determined, literature values are used, too). In the past, all RNG were significantly more expensive than natural gas; however, in 2022 RNG were cost competitive or even less expensive. Whether this will still be the case in the future, or to what extent, is uncertain. But at least, a lower price gap between NG and RNG than in the past is very likely.

*Table 3. Price ranges for various gases (EWI, 2022), (Krausler, 2018), (Liebetrau, 2021).*

| Gas | NG (past) | NG (2022) | NG (future) | LNG imports | Biomethane (AD) | Biomethane (Gasification) | Green H2 2020 | Green H2 2030 |
|---|---|---|---|---|---|---|---|---|
| €/MWh | 10-50 | 50-280 | 30-100 | 100-150 | 50-100 | 50-150 | 150-200 | 36-75 |

Obviously, the market environment for biomethane from FlexSNG looks promising. The price gap to natural gas is at least reduced, or maybe even closed. And besides the low-carbon intensity of biomethane, its energy dependence reducing character could justify a premium on natural gas price.

However, the uncertainty about the future European gas and energy supply, demand and prices remain high, and so the cost competitiveness of biomethane. As well, fuel switch may also affect the feedstock prices for biomass residues and wastes.

## 5.2 Incentives

In the past, biomethane was much more expensive than natural gas. Therefore, most European countries implemented incentive schemes to booster and support biomethane. Incentives are usually introduced to develop and support emerging technologies, products and markets, and are required at least till cost competitiveness is achieved with established ones. Consequently, a full developed market will not require incentives anymore, like an energy market considering all external costs for CO2. But until then, incentives have a steering effect for biomethane use, as some applications are preferred through financial support.

Incentives for biomethane comprise various different support mechanisms like investment supports, feed-in tariffs, green gas certificates, tax reliefs and mandatory quotas, supplemented by the CO2 trading system. The national support mechanisms are often a diverse combination of one or more incentives, reflecting the different national energy systems and policies. The situation is even made worse by the continuous adjustments of the incentives, driven by technology and market development as well as changing political objectives; not only for biomethane incentives itself, but also for competing alternatives, e.g. e-mobility in the transport sector. Providing a comprehensive overview of each national and European incentive mechanism is complex, time-consuming and would go beyond the scope of the deliverable.

Today, biomethane incentives are provided for its use for heat and electricity production, grid injection as well as transport fuel. A short general overview of support policy for the FlexSNG countries is given in paragraph 5.4. Currently, there are no dedicated incentives for biomethane from gasification in any country, but as well not excluded in countries with fixed feed-in tariffs, e.g. Germany for electricity or France for grid injection. This may change in the future due to current gas crisis.

## 5.3 Biomethane trading

As production, distribution and use usually involve different entities, biomethane (and all other gases) have to be traded between them. Trading of biomethane differs from classic natural gas trading due to the guarantee of origin. If renewable and fossil gas are separated physically, it is rather simple. Bio-CNG and bio-LNG is delivered by truck or vessel, as well the belonging renewable and sustainability certificates.

In contrast, the distribution through the gas grid mix fossil and renewable gases. The quantities of biomethane fed into the grid must be documented with the corresponding legally required sustainability and renewable properties from production to use. These properties result essentially from the legal framework conditions, in particular from REDII. In the past ten years, many biomethane producing countries built up registry systems to enable biomethane trading. Typically, such a biomethane registry is supervised by an authorized legal entity, e.g. The German Energy Agency (dena) or the Danish electricity and gas grid operator Energinet. Producers, traders and consumers of biomethane can document their injected quantities in gas grid, and all utilisation options remain open to producers and traders. After confirmation of the information on production conditions by independent experts, the quantities can be assigned to a consumption and thus proof can be provided without gaps between feed-in and withdrawal. So, biomethane trading is already working on national level, but differences between the national systems hinder cross-border trading. Furthermore, market imbalances caused by double-counting of CO2 reductions and windfall profits due to double incentives (e.g. support for production in Denmark and support for biomethane consumption in Sweden) have to be avoided.

The European cross-border trade in general in Europe is still at its infancy, but existing and growing (Figure 2). Until 2021, cross-border biomethane trade relied on bilateral agreements between some countries (or their authorities), mainly between Denmark and Sweden as well as Germany, UK and Denmark with Switzerland (REGATRACE, 2020).

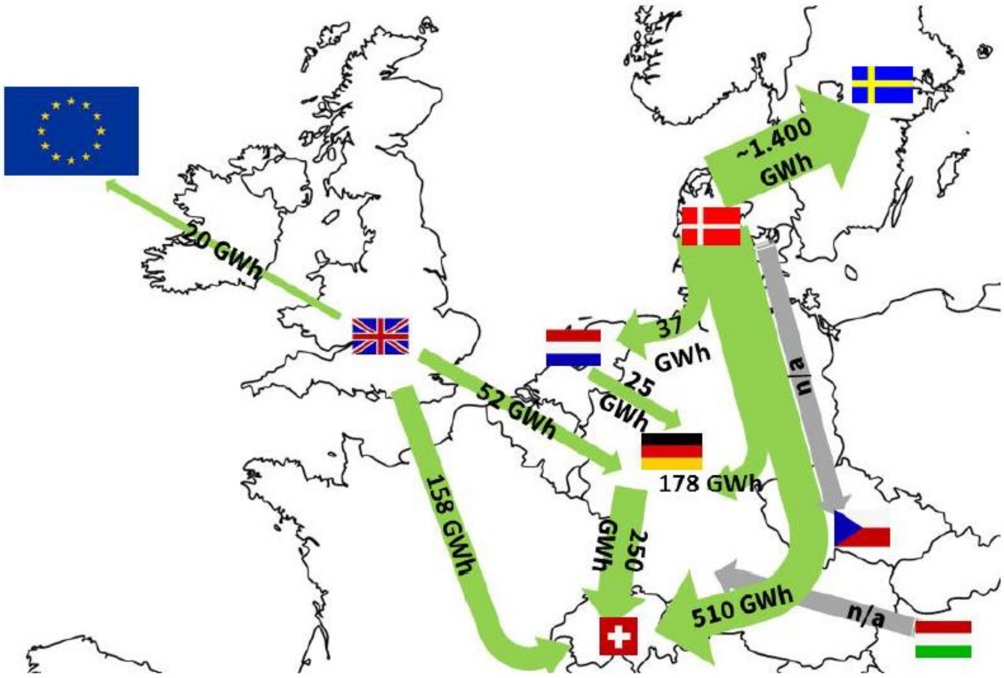


*Figure 2. European biomethane trade in 2020 (dena, 2021).*

In 2021, a European biomethane trade system started by the European Renewable Gas Registry (ERGaR). In 2022, 1,4 TWh biomethane were traded via this system, in contrast to only 20 GWh a year ago (ERGaR, 2023). ERGAR was founded in 2016 to facilitate cross-border trading and develop a common market for RNG. The recently finished H2020 projects REGATRACE (REGATRACE, 2022) as well as its predecessor project BIOSURF (BIOSURF, 2018) aimed to develop a European gas trading system for RNGs based on National biomethane registries. As main outcome, the project partners (national biogas registries, gas TSOs & DSOs, associations and other major gas market stakeholders) agreed on a common tradeable standard between them (Certificates of Origin, CoO). In contrast to REDII GoO, this system is open for private sustainability schemes as well (ERGaR, 2023). The mass balancing of biomethane is handled by considering the gas grid as one physical unit; so, a physical gas grid connection is mandatory.

Biomethane trading offers a promising option for FlexSNG concept due to the significantly enlarged market, reducing the uncertainty about future gas and biomethane demands. The Nordic countries already achieved a significant greening of their gas supply, and with increasing e-mobility the fuel demand in transport will decrease. In contrast, the feedstock potential in those countries is huge. A base case

100 MW FlexSNG plant delivers about 0,5 TWh/y biomethane, such amounts could be hard to place at future smaller markets.

## 5.4 Bio-CNG and Bio-LNG

Besides grid feeding, biomethane is also distributed and used in compressed (bio-CNG, or synonymously compressed biomethane, CBM) or liquefied (Bio-LNG, or synonymously liquefied Biomethane, LBM) form. However, the compression to CNG or liquefaction to LNG increase the productions costs of biomethane, in contrast to the negligible grid injection costs. The additional part of the production cost by compression to CNG are calculated to be around 4 €/MWh and for liquefaction to 8 €/MWh for a base case plant capacity of 100 MW (RES2CNG, 2019). CNG and LNG are also options for energy production in rural remote areas without grid network connection, e.g. Greek or French islands or regions with low population density, e.g. in Canada or Northern Scandinavia. However, the main market for bio-CNG and bio-LNG remains the transport sector.

As electrification of the transport sector has started and internal combustion engines will be banned for cars and vans from 2035. Consequently, the fuel demand for transport will decrease gradually over the next decades. However, some sectors are hard-to-electrify: the long-distance heavy-duty vehicles, the maritime and the aviation sector. Latter one is challenging for gaseous fuels due to their low-energy density and safety concerns. Therefore, biomethane will only fuel trucks and vessels in a long-term perspective. In the short and mid-term, biofuels are bridging the fossil to the electricity era for transport.

Sustainable biofuels cause lower CO2 emissions than fossils, and gaseous fuels are cleaner fuels than liquid ones. Bio-CNG/LNG combine both advantages; therefore, both are gaining more and more interest in recent years. The higher energy density of LNG makes it more attractive for the long-distance transport sector for trucks and vessels, whereas CNG is more suitable for light vehicles.

Natural gas is already used as transport fuel today (market share 2%), but its deployment is quite different between the European countries; and so for biomethane as well. The current situation for gaseous fuels is shown in Figure 3. A short overview about the current situation of gaseous fuels is given in Table 4.

.

*Table 4. NG and biomethane figures in transport sector (EBA, 2022) (Eurostat, 2021) (NGVA, 2022).*

| Country | Biomethane production (GWh/y) | Thereof used for transport (GWh/y) | NG use in transport (GWh/y) | Bio-share in gas-fueled transport | Fueling stations | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | CNG | | LNG | |
| | | | | | total | Bio | total | Bio |
| Denmark | 5683 | 0 | 128 | 0% | 0 | 0 | 0 | 0 |
| Finland | 156 | 156 (100%) | 215 | 42% | 67 | 67 | 11 | 11 |
| France | 4337 | 460 (11%) | 2247 | 17% | 0 | 0 | 153 | 153 |
| Germany | 12800 | 1000 (8%) | 5501 | 15% | 980 | 980 | 29 | 29 |
| Greece | 0 | 0 | 211 | 0% | 23 | 23 | 0 | 0 |
| Italy | 2000 | 2000 (100%) | 11248 | 15% | 1542 | 1542 | 126 | 126 |
| Sweden | 1508 | 1101 (73%) | 100 | 92% | 272 | 272 | 26 | 26 |
| UK | 6200 | 175 (3%) | n.a. | n.a. | 21 | 21 | 12 | 12 |
| Canada | 2000 | 0 | n.a. | n.a. | 36 | 0 | 4 | 0 |

Today, CNG is still more widespread than LNG, but the LNG market is growing fast. The biggest market by far is Italy with around 1 Mio natural gas vehicles. The highest biomethane market penetration is in the Nordic countries, but the largest markets are Italy and Germany. In Europe, 4200 CNG and 589 LNG fueling station are in operation, of which 1900 offer already Bio-CNG and 125 Bio-LNG. The gas fueling station network is covering most of the continent meanwhile. The bio-LNG market is also growing fast, with ambitious expansion targets in the next years. The number of 15.000 LNG trucks today is estimated to multiply to 2800.000 in 2030 (EBA, 2022). In parallel, the LNG fueling network expands fast along the highways for the heavy goods traffic, in particular in Germany, Netherlands and Italy. A similar development is observed in the maritime sector, but the need for higher density as well as the longer lifetimes of vessels favors liquid fuels like green or e-methanol.

## 5.5 Country Outlook

As discussed before, the current situation varies strongly in the different countries. As an example, in most countries the RNG share in the gas grid is less than 1%; however, in some Nordic countries its share is already significant with up to 25%. The use of biomethane is also quite diverse (Figure 3), whereas electricity production dominates in Germany and heat in the UK, it is the fuel use in Italy.

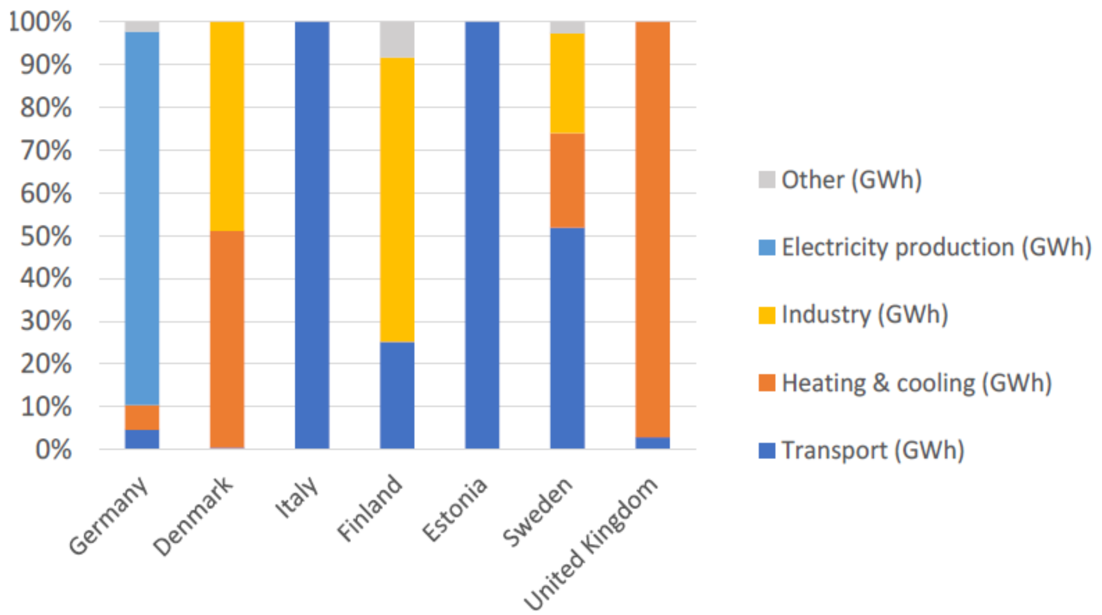


*Figure 3. Biomethane use per sector for some EU countries (REGATRACE, 2022).*

Some reasons for these huge discrepancies are the relevance of natural gas within the national energy mix, differing national incentives for biomethane use and the development of the biomethane sector.

Subsequent, a short overview for the case study countries is given.

**Denmark:**

The role of natural gas in Denmark is decreasing, the domestic production as well the consumption (12% of primary energy demand; 25 TWh/y). Denmark turned from a gas exporting to a gas importing country during the last decade. The gas grid with a length of 17.000km is an important transit network for North Sea sources to Sweden, Baltic and Poland.

Despite the declining natural gas share in the Danish Energy mix, Denmark is one of the largest biomethane producers in Europe (5,6 TWh/y). The former onsite electricity production from biogas changed in the last decade to upgrading to biomethane. Therefore, the biomethane share in the gas grid is high with around 25%. Biomethane is used mainly for heating (domestic and district). For transport, gaseous fuels are meaningless in the transport sector.

Denmark is the biggest biomethane exporter in Europe, mainly exported to Sweden, due to the support schemes for both countries (investment support in Denmark, consumption supported in Sweden.

*Table 5. Country fact sheet Denmark.*

| **Country facts** | | | |
|---|---|---|---|
| **Population** | 5,9 Mio | **Density of population** | 136 persons/km$^3$ |
| **Area** | 42.920 km$^2$ | **Length gas grid** | 17000 km |
| **Forest area** | 6.240 km$^2$ | **Agricultural land** | 26200 km$^2$ |
| **Waste amount** | 20 Gt | **thereof MSW** | 4,6 Gt/y |
| **Gas market data** | | | |
| **Gas consumption** | 25 TWh/y | Thereof Transport<br>Domestic<br>Industry<br>Energy<br>Commercial & Public Service | <1%<br>21%<br>38%<br>28%<br>11% |
| **NG share of Primary energy** | 12,5% | **NG share of Final Energy** | 9% |
| **Gas prices HH** | 64 €/MWh | **Gas prices Ind** | 25 €/MWh |
| **Electricity price HH** | 290 €/MWh | **Electricity price Ind** | 73 €/MWh |
| **Biomethane** | 5,6 TWh/y | **Thereof Transport** | 0% |
| **CNG stations** | 21 | **LNG stations** | 1 |
| **LNG terminals** | 0 | **NG passenger cars** | 137 |

**Finland:**

Natural gas is less important than in many other European countries (around 27 TWh/y resp. 5% of PE), mainly used in Industry and Energy sector. The gas grid is limited to the urban areas in the southern part of the country, and recently connected via Baltic countries with Central Europe. Biomethane production from AD is growing, nearly equally shared between off-grid and grid injection. Due to missing gas grid in less populated remote areas, CNG and LNG infrastructure is common. The Finnish biomethane policy favors the use for transport, support investment for biomethane plants as well as for heavy duty gas vehicles.

*Table 6. Country fact sheet Finland.*

| | | | |
|---|---|---|---|
| **Country facts** | | | |
| **Population** | 5,6 Mio | **Density of population** | 17 persons/km$^3$ |
| **Area** | 338.460 km | **Length gas grid** | 1150 km |
| **Forest area** | 224.090 km$^2$ | **Agricultural land** | 22.700 km$^2$ |
| **Waste amount** | 116 Gt | **thereof MSW** | 3,4 Gt/y |
| **Gas market data** | | | |
| **Gas consumption** | 27 TWh/y | Thereof Transport | 1% |
| | | Domestic | 3% |
| | | Industry | 38% |
| | | Energy | 42% |
| | | Commercial & Public Service | 16% |
| **NG share of Primary Energy** | 5% | **NG share of Final Energy** | 7% |
| **Gas prices HH** | 55 €/MWh | **Gas prices Ind** | 39 €/MWh |
| **Electricity price HH** | 177 €/MWh | **Electricity price Ind** | 67 €/MWh |
| **Biomethane** | 156 GWh/y | **Thereof Transport** | 50% |
| **CNG stations** | 66 | **LNG stations** | 15 |
| **LNG terminals** | 3 | **NG passenger cars** | 6460 |

**France:**

Due to the huge nuclear capacity, natural gas is less prominent for the French energy mix than for most other big industrial countries (480 TWh/y, resp. 20% of primary energy). Natural gas is mainly used in industry and for domestic heating, the gas grid covers most of the country. The biomethane production grew fast to 4,4 GWh biomethane in 2021. All biomethane is fed into the gas grid (1% total gas consumption), with the expansion target of 10% in 2030. A fixed feed-in tariff of around 100 €/MWh for biomethane is provided, but it is planned to decrease over time to 60 €/MWh in 2028.

About 10% of the annual biomethane production is used as fuel, resulting in an overall 20% share of biomethane of CNG/LNG consumption, mainly used for buses and heavy-duty vehicles.

*Table 7. Country fact sheet France.*

| **Country facts** | | | |
|---|---|---|---|
| **Population** | 66,1 Mio | **Density of population** | 120 persons/km$^3$ |
| **Area** | 549.081 km$^2$ | **Length gas grid** | 1150 km |
| **Forest area** | 172.530 km$^2$ | **Agricultural land** | 285.534 km$^2$ |
| **Waste amount** | 315 Gt | **thereof MSW** | 37 Gt/y |
| **Gas market data** | | | |
| **Gas consumption** | 483 TWh/y | Thereof Transport<br>Domestic<br>Industry<br>Energy<br>Commercial & Public Service | 0,4%<br>30%<br>32%<br>19%<br>17% |
| **NG share of Primary Energy** | 16% | **NG share of Final Energy** | 20% |
| **Gas prices HH** | 69 €/MWh | **Gas prices Ind** | 27 €/MWh |
| **Electricity price HH** | 195 €/MWh | **Electricity price Ind** | 85 €/MWh |
| **Biomethane** | 4,4 TWh/y | **Thereof Transport** | 11% |
| **CNG stations** | 208 | **LNG stations** | 70 |
| **LNG terminals** | 4 | **NG passenger cars** | 1071 |

**Germany:**

Gas plays an important role in German energy mix, Germany is the biggest gas consumer in Europe (1000 TWh/y, resp. 30% of primary energy). Less than 1% is used for transport, the lion's share is used for energy, heat and industry (incl. material use in chemical industry) with around 30% each. The German gas infrastructure has a length of more than 500.000 km and a storage capacity of 280 TWh.

The German biomethane production of 13 TWh is overwhelmingly fed to the grid, mainly used for electricity production. The most important funding scheme for biomethane EEG (Renewable Energy Sources Act) focuses on electricity production for biomethane, but changing from baseload to flexible electricity production. There's no feed-in tariff for biomethane. 1 TWh biomethane is used in the transport sector.

Gas for transport is not very common in Germany, but growing (10 TWh/y), but 1 TWh biomethane is used in the transport sector. Almost all CNG fueling stations provide Bio-CNG as well. Furthermore, the LNG infrastructure along the motorways is expanding. The growing interest on bio-LNG, in particular for long-distance heavy goods transports, comes due to mandatory CO2 certificates for fossil fuels in the transport sector since end of 2021.

*Table 8. Country fact sheet Germany.*

| Country facts | | | |
|---|---|---|---|
| **Population** | 83,8 Mio | **Density of population** | 235 persons/km$^3$ |
| **Area** | 357.021 km$^3$ | **Length gas grid** | 511.000 km |
| **Forest area** | 114.190 km$^2$ | **Agricultural land** | 183.140 km$^2$ |
| **Waste amount** | 401 Gt | **thereof MSW** | 54 Gt/y |
| **Gas market data** | | | |
| **Gas consumption** | 999 TWh/y | Thereof Transport<br>Domestic<br>Industry<br>Energy<br>Commercial & Public Service | 0,2%<br>31%<br>37%<br>12%<br>13% |
| **NG share of Primary Energy** | 31% | **NG share of Final Energy** | 27% |
| **Gas prices HH** | 65 €/MWh | **Gas prices Ind** | 24 €/MWh |
| **Electricity price HH** | 319 €/MWh | **Electricity price Ind** | 91 €/MWh |
| **Biomethane** | 13 TWh/y | **Thereof Transport** | 7,5% |
| **CNG stations** | 776 | **LNG stations** | 151 |
| **LNG terminals** | 1 (4) | **NG passenger cars** | 82309 |

**Greece:**

Natural gas is gaining more and more importance in the Greece energy system during the past decade (15% of primary energy, resp. 70 TWh/y), in particular for electricity production. So far, no biomethane is produced, not least due to missing financial support. However, the biogas funding scheme of feed-in tariffs for electricity production favors power production. The gas grid is rather small and limited in the urban continental regions. Due to the large number of Greek islands, the energy system is much more decentralized than in other European countries, with a lot of off-grid and local network solutions.

*Table 9. Country fact sheet Greece.*

| **Country facts** | | | |
|---|---|---|---|
| **Population** | 10,3 Mio | **Density of population** | 78 persons/km$^3$ |
| **Area** | 131.960 km$^3$ | **Length gas grid** | 3.901 km |
| **Forest area** | 39.018 km$^2$ | **Agricultural land** | 58.744 km$^2$ |
| **Total waste amount** | 25 Gt | **thereof MSW** | 5,4 Gt/y |
| **Gas market data** | | | |
| **Gas consumption** | 70 TWh/y | Thereof Transport<br>Domestic<br>Industry<br>Energy<br>Commercial & Public Service | <0,1%<br>12%<br>15%<br>65%<br>8% |
| **NG share of Primary Energy** | 15% | **NG of Final Energy** | 8% |
| **Gas prices HH** | 45 €/MWh | **Gas prices Ind** | 23 €/MWh |
| **Electricity price HH** | 168 €/MWh | **Electricity price Ind** | 89 €/MWh |
| **Biomethane** | 0 TWh/y | **Thereof Transport** | 0% |
| **CNG stations** | 28 | **LNG stations** | 0 |
| **LNG terminals** | 1 | **NG passenger cars** | n.a. |

**Italy:**

The relevance of natural gas for Italy is high (40% of primary energy resp. 800 TWh/y), with energy and domestic heating as main consumers. As well, natural gas plays a significant role in the transport sector (> 1 Mio natural gas vehicles), resulting in a well-developed CNG and LNG infrastructure. Biomethane production increased in recent years to more than 2 TWh in 2021. The main driver was the change of biogas funding schemes, switching from electricity production from biogas to biomethane upgrading. The major part of biomethane is injected to the gas grid, and completely used as transport fuel.

*Table 10. Country fact sheet Italy.*

| Country facts | | | |
|---|---|---|---|
| **Population** | 60,6 Mio | **Density of population** | 201 persons/km$^3$ |
| **Area** | 302.068 km$^2$ | **Length gas grid** | 3.901 km |
| **Forest area** | 95.661 km$^2$ | **Agricultural land** | 130.290 km$^2$ |
| **Total waste amount** | 175 Gt | **thereof MSW** | 30 Gt/y |
| **Gas market data** | | | |
| **NG consumption** | 808 TWh/y | Thereof Transport<br>Domestic<br>Industry<br>Energy<br>Commercial & Public Service | 2%<br>29%<br>15%<br>42%<br>12% |
| **NG share of Primary Energy** | 40% | **NG of Final Energy** | 43% |
| **Gas prices HH** | 70 €/MWh | **Gas prices Ind** | 23 €/MWh |
| **Electricity price HH** | 226 €/MWh | **Electricity price Ind** | 94 €/MWh |
| **Biomethane** | 2,2 TWh/y | **Thereof Transport** | 100% |
| **CNG stations** | 1550 | **LNG stations** | 19 |
| **LNG terminals** | 3 | **NG passenger cars** | 984964 |

**Sweden:**

Despite the very low relevance of natural gas for Sweden, its biomethane market is well developed, resulting in a 12% share of biomethane in the natural gas market (1,5 TWh/y of 15 TWh/y). Natural gas is predominantly used in industry. Swedish gas grid is located only in the southwest of the country (connected via Denmark with the Central European gas grid network). Therefore, CNG and LNG infrastructure is already established, as well as local gas grids, and only a minor part of biomethane plants have a grid connection. Biomethane is mainly used as transport fuel and to lower extent for heating networks.

*Table 11. Country fact sheet Sweden.*

| **Country facts** | | | |
|---|---|---|---|
| **Population** | 10,3 Mio | **Density of population** | 23 persons/km$^2$ |
| **Area** | 528.861 km$^2$ | **Length gas grid** | 3.000 km |
| **Forest area** | 279.800 km$^2$ | **Agricultural land** | 31.335 km$^2$ |
| **Total waste amount** | 152 Gt/y | **thereof MSW** | 4,3 Gt/y |
| **Gas market data** | | | |
| **NG consumption** | 13 TWh/y | Thereof Transport<br>Domestic<br>Industry<br>Energy<br>Commercial & Public Service | <1%<br>3%<br>68%<br>12%<br>17% |
| **NG share of Primary Energy** | 2% | **NG of Final Energy** [4] | 1,5% |
| **Gas prices HH** | 123 €/MWh | **Gas prices Ind** | 445 €/MWh |
| **Biomethane** | 1,5 TWh/y | **Thereof Transport** | 73% |
| **Electricity price HH** | 211 €/MWh | **Electricity price Ind** | 71 €/MWh |
| **CNG stations** | 209 | **LNG stations** | 27 |
| **LNG terminals** | 3 | **NG passenger cars** | 13735 |

**UK:**

Natural gas is an important energy factor in UK (40% of primary energy resp. 860 TWh/y), due the domestic North Sea gas production. However, UK turned in the last years to net gas importing country because of the more and more exploited gas fields. The gas grid is quite large and connected to Central Europe network. Main gas consumers are households and the energy sector. UK is Europe's second largest biomethane producer (>6 TWh/y). The funding schemes promote the grid injection with use for Renewable Heat production. Therefore, bio-CNG and Bio-LNG are neglectable, as well is the use of gas for transport not very common.

*Table 12. Country fact sheet UK.*

| **Country facts** | | | |
|---|---|---|---|
| **Population** | 69,0 Mio | **Density of population** | 283 persons/km$^2$ |
| **Area** | 243.610 km$^2$ | **Length gas grid** | 283.000 km |
| **Forest area** | 31.900 km$^2$ | **Agricultural land** | 175.623 km$^2$ |
| **Total waste amount** | 282 Gt | **thereof MSW** | 32 Gt/y |
| **Gas market data** | | | |
| **NG consumption** | 860 TWh/y | Thereof Transport<br>Domestic<br>Industry<br>Energy<br>Commercial & Public Service | <0,1%<br>37%<br>18%<br>33%<br>11% |
| **NG share of Primary Energy** | 40% | **NG of Final Energy** [4] | 42% |
| **Gas prices HH** | 478 €/MWh | **Gas prices Ind** | 25 €/MWh |
| **Electricity price HH** | 220 €/MWh | **Electricity price Ind** | 107 €/MWh |
| **Biomethane** | 6,2 TWh/y | **Thereof Transport** | 3% |
| **CNG stations** | 14 | **LNG stations** | 14 |
| **LNG terminals** | 3 | **NG passenger cars** | 409 |

**Canada:**

Gas plays an outstanding role in Canada, not only for its domestic energy mix. The natural gas production exceeds the demand by far, making Canada to a net gas exporting country. The national gas infrastructure comprises a grid length of 600.000 km all over the country. Two-thirds of the Canadian households are heated with gas. The natural gas share in electricity production is slowly increasing (to 10% in 2021). In total, the share of natural gas in final energy demand is around 36% or 1200 TWh/y (CGA, 2023).

In contrast, biomethane production is quite low (2 TWh in 2021), but increasing driven by provincial green quota mandates in British Columbia and Quebec as well the Clean Fuel Standard introduction. Natural gas and biomethane are neglectable fuels in the transport sector at the moment (NGV share < 0,01% of total vehicles). However, LNG is attracting more and more interest, not least for maritime sector (CNGVA, 2019).

*Table 13. Country fact sheet Canada.*

| | | | |
|---|---|---|---|
| **Country facts** | | | |
| **Population** [1] | 39 Mio | **Density of population** | 4 persons/km² |
| **Area** | 9.879.750 km² | **Length gas grid** | 571.000 km |
| **Forest area** [1] | 3.469.281 km² | **Agricultural land** | 593040 km² |
| **Total waste amount** [3] | 36 Gt/y | thereof MSW | 15 Gt/y |
| **Gas market data** | | | |
| **NG consumption 2020** [4] | 1230 TWh/y | Thereof Transport<br>Domestic<br>Industry<br>Electricity<br>Commercial & Public Service | < 0,1%<br>19%<br>43%<br>19%<br>16% |
| **NG of Primary Energy** [5] | 32%% | **NG of Final Energy** [4] | 36% |
| **Gas prices** | 20 €/MWh | | |
| **Biomethane production** [6] | 2 TWh/y | Thereof fuel | n.a. |
| **CNG stations** [7] | 36 | **LNG stations** [7] | 4 |
| **LNG terminals** | 1 (18 in planning phase) | | |

# 6 Conclusions

The RNGs biomethane and e-methane as well as hydrogen are low-carbon substitutes for natural gas and able to replace natural gas in the energy system. Bio- and e-methane are drop-in fuels, requiring no major changes of the existing infrastructures, contrast to hydrogen. Recently, a ten-fold RNG production target till 2030 was announced (EC, 22). So far, the RNG share in most European gas network is below 1% (with exception of the Scandinavian up to 25%), but targeted to reach 10% by 2030 in average. As only biomethane from anaerobic digestion is available so far and the additional potential is limited, certain amounts have to come from alternative sources. Although the syngas and methanation route is not commercially applied today due to economic reasons, it is technically feasible and ready for market introduction. The experience gained from market introduction and development for biogas upgrading can provide valuable insights for biomethane from gasification developments. However, the disruptive 2022 developments on the European gas markets make any prospective analysis highly challenging, as gas prices are highly fluctuating, and the supply and so likely the demand structures are changing.

Biomethane can be distributed either through an existing gas network or in the form of CNG and LNG. Both options are already in use today. The technical and regulatory standards for natural gas allow the feeding of biomethane into gas grids, if certain minimum quality criteria are met. However, these gas quality criteria are not fully harmonized in Europe yet, in particular the energy and the sulfur content within different gas grids can still vary. Regarding biomethane from FlexSNG, the gas quality criteria for grid injection are no obstacle and can be achieved by gas cleaning and upgrading easily. The same applies for the use of biomethane as transport fuel in form of CNG and LNG, both quality standards and sustainability constraints imposed by REDII can be fulfilled, even if the final biomethane quality is not yet defined.

The disruptive 2022 developments on the European gas market makes the detailed analysis of the finding of promising future markets for biomethane highly difficult, as the market environment for RNG has changed significantly. In the past, biomethane was much more expensive than natural gas, the main obstacle for displacing natural gas. To lower the price gap, incentive schemes for biomethane production are provided. The funding schemes reflect the different roles of natural gas and national energy policies for a country. The schemes comprise either investment support for production units, for gas grid feeding or the biomethane consumption for electricity production, heat and the use as transport fuel. While during the two last decades the focus was mainly on electricity production, meanwhile the hard-to-abate sectors of transport are targeted by support policies. This development is driven by European and national mandates to increase the share of biofuels in the transport sector.

The start of the European Renewable Gas Registry (ERGaR) with its Certificates of Origin Scheme looks promising to accelerate the European trading of RNG, with stimulating effects due to the increasing market volume. In particular for biomethane from gasification, this development can be seen as rather positive. The typical envisaged plant capacity of 100 MW for one single FlexSNG plant is much larger than for a biomethane AD plant. To place such amounts of biomethane at one single small national gas market, as it would be the case for many European countries, could cause imbalances; but the risks are decreased by the option to address the whole European natural gas market.

Considering a long-term perspective, the hard-to electrify sectors for long-distance transport (heavy trucks and maritime, less aviation) are the most promising market for biomethane, as well as industries with demand for high temperature heat, e.g. cement, chemical or glass production. The growth of renewable electricity production accompanied by the electrification of heat as well transport sector will reduce the demand for gas in both sectors. Furthermore, an increasing availability of cheap green hydrogen are will reduce the biomethane market as well. How fast these developments will proceed, is unknown at the moment. Until then, biomethane can replace immediately natural gas and contribute to the reduction of CO2 and the dependency of energy imports.

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# 8 Appendix: National biomethane grid injection and natural gas standards

| Criteria | CD [1] | DK {2] | FI [3] | FR [4] | DE [5] | IT [6] | SE [7] | UK [8] |
|---|---|---|---|---|---|---|---|---|
| HHV [MJ/Nm$^3$] | ≥36,0 various upper limits 41-60 | | | 38,5-46,1 H 34,2-37,8 L | 30,2-47,2 | 34,95-45,28 | | 36,9-42,3 |
| Relative density | | 0,55-0,75 | 0,55-0,7 | 0,55-0,75 | 0,55-0,75 | 0,555-0,700 | 0,55-0,75 | 0,55-0,75 |
| Wobbe Index [MJ/Nm$^3$] | | 50,76 - 55,8 | 49,54-56,92 | 49,1- 56,5 H 43,2- 47,0 L | 46.1-56.5 (H 37.8-46.8 (L)) | 47.31-52.33 | | 46,5-52,85 |
| CH [mol%]4 | | | ≥ 96 | | ≤ 95 (H) ≤ 90 (L) | | | |
| O2 [mol%] | < 0,4 vol% | ≤ 0,5 | ≤ 1 | ≤ 0,75 (H) ≤ 3 (L) | ≤ 3 ≤0,001 (storage) | ≤ 0,6 | | ≤ 1(≤ 38 bar) 0,2 (≤ 75 bar) |
| CO2 [mol%] | < 2 vol% | ≤ 3 | ≤ 2,5 | ≤ 3,5 (H) ≤ 11,7 (L) | ≤ 10 | ≤ 2,5 | | ≤ 2,5 |
| CO [mol%] | | | ≤ 0,05 | ≤ 0,2 | - | ≤ 0,1 | | |
| H2 [mol%] | | | ≤ 2 | ≤ 6 | ≤ 10 | ≤ 1 Vol% | | ≤ 0,1 |
| N2 [mol%] | max. < 4 vol% | | ≤ 2,5 | | | | | |
| Total inerts | < 4vol% | | | | | | | |
| H20 [mg/Nm$^3$] | | Dewpoint -8°C (70bar) | ≤ 3 | Dewpoint -5°C | 200 (≤ 10 bar) 50 (<70bar) | Dewpoint -5°C | Dewpoint -8°C (70bar) | Dewpoint -10°C (≤ 85 bar) |
| H2S [mg/Nm$^3$] | | ≤ 5 | Residuals | ≤ 5 | ≤ 5 | ≤ 5 | | ≤ 5 |
| S-mercaptans | | ≤ 6 mg/Nm$^3$ | | ≤ 6 mg/Nm$^3$ | ≤ 6 mg/Nm$^3$ | - | ≤ 6 mg/Nm$^3$ | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Total S | | ≤50 [mg/Nm³] | | ≤30[mg/Nm³] | ≤10[mg/Nm³] | ≤150[mg/Nm³] | | ≤50[mg/Nm³] |
| NH3 [mg/Nm³] | | ≤ 3 | | ≤ 3 | | ≤ 10 | ≤ 3 | |
| Hydrocarbon dew point | | 2 °C (≤ 70 bar) | | 2 °C (≤ 70 bar) | -2 °C (≤ 70 bar) | only LPG ≤ 5 (≤ 70 bar); | 2 °C (≤ 70 bar) | -2°C (≤ 5 bar) |
| Total Siloxanes | | ≤ 1 mg/Nm³ | Residuals | | | ≤ 1 mg/Nm³ | ≤ 1mg/Nm³ | |
| Cl/F-Hydrocarbons [mg/Nm³] | | | Residuals | ≤ 1 Cl<br>≤ 10 F | | ≤ 4 | | ≤ 1,5 mol% |

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