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Overview of production routes and end-uses of renewable gases and existing policy frameworks in advanced European and Mission Innovation countries.

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GREENMEUP

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Summary of the GreenMeUp project

GreenMeUp – Green Biomethane Market Uptake is a Horizon Europe project that aims at providing a basis for policy-makers and stakeholders to develop more informed renewable energy policies and country-tailored market uptake measures, in order to improve and complement existing biomethane policy in Europe.

The core activity of GreenMeUp is to reduce the gap between countries with higher rates of biomethane production and countries with lower development rates, by analyzing and comparing their framework conditions and market dynamics and promote enabling policies and measures at country level. The project aims at providing societal acceptance of the biomethane value chain through science-based evidence and tools.

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Introduction

In 2022, Europe has experienced the consequences of the extremely volatile price of fossil gas. The excessive dependence of the European Union (EU) on external energy supplies from Russia is hindering the energy security and inflating energy bills of thousands of European households and industries. The EU is determined to steer away from Russian gas while holding climate change mitigation efforts up, by expediting the production and uptake of renewable energy.

In this context, renewable gases, including biogas and biomethane, are becoming instrumental in shaping the future energy mix. Their deployment will reduce Europe's dependency on natural gas. Additionally, it will substantially contribute to an integrated net-zero energy system, encompassing the energy and agroecological transitions and helping Europe embrace circular economy. The biogas and biomethane industries are already providing 18.4 bcm of renewable gas to Europe. By 2050, it could provide up 167 bcm, covering 35-62% of 2050's gas demand.[1]

The GreenMeUp D1.1 identifies, lists, and quantifies existing production and use routes for biomethane. In terms of production routes, the total biomethane production is split into categories with a special focus on feedstock usage. Both anaerobic digestion and gasification routes are considered. Next, policies and market dynamics which are successful in achieving biomethane production and use were investigated. An evaluation of the different policy frameworks was made based criteria such as achieved production and perceived value of biomethane in the country. A distinction between direct and indirect support measures was made with attention to policy frameworks which highlight the positive externalities of biomethane production.

The overall aim of this report is to bring forward good practices and lessons learnt from countries having the highest market shares covering > 95% of biomethane produced in Europe (Germany, UK, Denmark, France, The Netherlands, Italy, Sweden, Norway, Switzerland and Austria) and to actively exchange practical knowledge and experience with a set of target countries with lower development rates in biomethane production (Greece, Spain, Poland, Latvia, Estonia and Czech Republic) which would benefit from a stronger biomethane market and policy measures.

The work is allocated in the following chapters:

Chapter 1, focuses on the European Policy Framework and the multiple regulations that shape the development of renewable energies, and consequently the biomethane sector, which is heavily influenced by the legal norms transposed into the national law at the Member State level.

Chapter 2, describes the European Biomethane Market, which is highly diversified among the EU countries.

Chapter 3, focuses on biomethane production routes in Europe, covering anaerobic digestion and gasification technologies, as well as the biogas compositions. .

Chapter 4 suggest ways for optimizing feedstock usages, by providing guidelines for optimizing efficiency of the feedstocks and introducing Mechanical and Pre-Treatment technologies.

[1] EBA Statistical Report 2022

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Chapter 5, presents the end-uses of biomethane, the technological options and the end-use sectors.

Chapter 6 is focused on best practices for biomethane supportive policies, by analyzing vision and targets, direct investment and production support, indirect production support, demand-side incentives and regulation enabling market access.

Chapter 7 is covering a country analysis for the biomethane markets in the 10 most advanced European countries, namely Germany, Italy, France, United Kingdom, Denmark, Switzerland, Austria, The Netherlands, Sweden and Norway.

Finally, Chapter 8 is focused on the overview of policy and financial framework, market status and production routes of renewable gases in Mission Innovation countries, namely Canada, china, India and USA. Text summaries were provided by the following participating members in our International Advisory Board.

For Canada:

- Nicolas Abatzoglou / University of Sherbrook and
- Warren Mabee / University of Queens in Canada

For China:

- Shizhong Li, MOST-USDA Joint Research Centre for Biofuels, Tsinghua University, China
- Yishui Tian, Academy of Agricultural Planning & Engineering, Ministry of Agriculture & Rural Affairs, China

For India :

- Ramakrishna Y B, Member Expert – Working group on Biofuels, Ministry of Petroleum & Natural Gas, Government of India and Chairperson – IFGE CBG Producers Form, on March 15, 2023.

For USA :

- Sam Lehr, Manager of Sustainability & Markets Policy with the Coalition for Renewable Natural Gas (RNG Coalition)

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Chapter 1: The European policy framework

At the European level, multiple regulations shape the development of renewable energies, thereby the national deployment of biogas respectively biomethane sector is heavily influenced by the legal norms transposed into the national law at the Member State level.

Being adopted in July 2021, the **Renewable Energy Directive (RED II)** foresees the increase from 32 % to 40 % as the RE target in the EU. The new Proposal as of May 2022 contains the pledge for the rise of the RE target up to 45 % in the light of the changing energy market, increased prices, and the need to phase-out Russian energy imports. The amendment of the Renewable Energy Directive (RED III) is currently subject of the trialogue negotiations.

Energy Taxation Directive (ETD) (2003/96/EC) shapes a common framework for energy taxation at the EU level, thus providing the groundwork to reach climate policy goals. Became effective in 2003, it defined structural rules and minimum duty rates for the taxation of energy (electricity, motor, and heating fuels). ETD becomes outdated though without reflecting first and foremost the EU's commitment of at least 55% reduction in greenhouse gas emissions by 2030. For this reason, as a part of "Fit for 55" package, a new revision proposal of the Directive was introduced in 2021 consisting of two-tier amendment. In accordance with that, a new structure of tax rates referring to the energy content and environmental performance of the fuels and electricity rather than to volume was set up as well as the taxable base was broadened by considering more products and by removing some of the current tax exemptions and reductions. However, certain reductions will remain, i.e., for electricity or advanced energy products produced from renewables. As a result, by the new categorization the most polluting fuels will be taxed the highest and the removed national exemptions will result in lower margins for the member states, which will make electricity and heat from fossil fuels more expensive and thus biomethane indirectly more competitive (European Commission, 2021[2]).

The **European Union Emissions Trading System (EU ETS)**, currently within the fourth trading phase (2021-2030), applies to the EEA-EFTA countries[3] and is about limiting the emissions in the power sector, energy-intensive industries, and the airlines operating between EEA-EFTA states. Fuels from advanced biomass (RED II Annex IX) are to receive the lowest tax rate among all energy sources, sustainable biomass at least a reduced rate. As a part of "Fit for 55" package, European Commission envisaged a revision of EU ETS in 2021 providing a set of the measures in order to low the emissions in the EU by at least 55 % referring to the 1990 levels by 2030. According to the proposed EU ETS II, the road transport and heat sector should become part of the new emissions trade to become effective in 2026 after two-year implementation period. Thereby contrary to EU ETS I, due to the missing zero-priced certificate allocation incentives for fuel savings resp. indirect competitive advantage for biomethane are provided by increasing the price of fossil alternatives, thus opting for low-emission technologies (UBA, 2021). Further, air transport sector should be amended, and involvement of the maritime transport should provide an extension of the ETS application areas as well.

REPowerEU plan (A plan to rapidly reduce dependence on Russian fossil fuels and fast forward the green transition) represents formally a non-binding strategy document released in May

[2] https://ec.europa.eu/commission/presscorner/detail/en/qanda_21_3662

[3] EEA = European Economic Area comprise EU member states and three EFTA (European Free Trade Association) states Iceland, Liechtenstein, and Norway

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2022 aiming for ending the EU's dependence on Russian fossil fuels and tackling the climate crisis. The main aspects include:

- increased energy savings (raising target from 9 to 13 % of the EU Energy Efficiency Directive in light of the "Fit for 55" package).
- diversification of energy imports into the EU (liquefied natural gas).
- substitution of fossil energy through the accelerated expansion of power generation capacities from wind and PV, hydrogen (generation and import), and biomethane.

It proposes changes, e.g., to the RED (increase the 2030 target for RE from 40 % to 45 % under the "Fit for 55" package) and to tenfold biomethane production by 2030, aiming to achieve a target of at least 35 bcm (350 TWh) of an annual biomethane production by 2030 as a part of the Biomethane Action Plan, among others through the incentives under the Common Agricultural Policy (CAP) and the launch of the new Biomethane Industrial Partnership (BIP). In order to do so, more biogas must be produced and existing biogas converted to biomethane with the need for more incentives to build up new plants and provide biomethane by repowering existing plants in the EU (European Commission, 2022[4]).

[4] https://ec.europa.eu/commission/presscorner/detail/en/IP_22_3131

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Chapter 2: The European Biomethane Market

Biogas production in Europe preceded biomethane production. Whereas the biogas industry has stagnated over the past decade, biomethane production continues to grow. 2020 saw a biomethane production in Europe of 31 TWh or 2.9 bcm; this figure grew to 37 TWh or 3.5 bcm in 2021, representing an increase of 20%. Further increase is expected beyond 2021, as a record number of new biomethane plants started production in 2021 and are due to become fully operational within 2022 and 2023.

Figure 1 Combined Biomethane and Biogas production in Europe (TWh). Source: EBA Statistical Report

Relative to each country's total gas consumption in 2021, Figure 2 below shows biomethane and biogas production in European countries, indicating the percentage of each country's gas consumption which could be covered by biomethane if all the country's biogas were to be upgraded. The figure clearly shows that countries such as Denmark and Sweden are well on track to replace their natural gas consumption with biomethane. In fact, Energinet calculated that by September 2022, Denmark had already reached a biomethane production amounting to 29.7% of its natural gas consumption, and the share of biogas and biomethane in its energy mix

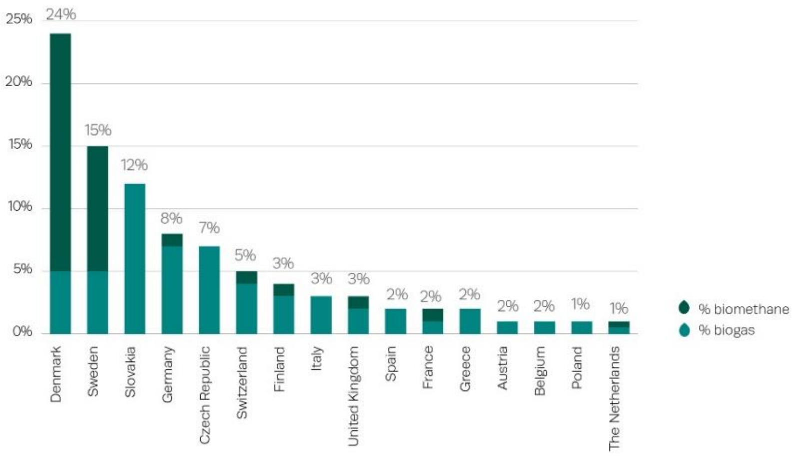

Figure 2 Biomethane and biogas production relative to gas consumption in 2021, top 16 countries

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is increasing every month[5]. Such increasing trends in production can also be seen in other European countries.

Biogas is most often used in a CHP to generate both electricity and heat. Biomethane, on the other hand, can be used for a variety of end-use applications, as it can replace all the end-uses of natural gas. The production and end-uses of biomethane are influenced by market mechanisms, regulations, and support mechanisms, all of which vary between countries.

Over the last decade, the delivery of dispatchable power and heat from biogas has been very important and its role will continue to a certain extent. The current trend places the emphasis squarely on biomethane production, however, and it is expected that this tendency will be amplified in the coming decade: biomethane is a versatile energy carrier, suitable for a range of sectors, including transport, industry, power, and heating.

Countries like Denmark, Sweden, Norway, and Estonia report more biomethane production compared to biogas without upgrading. In the case of Estonia, they are projecting a complete switch of all biogas plants to biomethane production by the end of 2022. Other countries such as France, the Netherlands, Italy, Switzerland, and the UK are showing the same trend of increasing biomethane production year in year out. Hence the future of biomethane production in Europe is on an uptrend and this can be expected to continue in the coming years. Figure 3 shows the 10 European countries with the highest biomethane production in 2020.

The majority of biogas and biomethane production in Europe comes from agricultural plants. This accounts for 64% of the total production. The second biggest source of biomethane production is organic municipal solid waste (11%); the second biggest source of biogas production is landfill (14%). Biomethane facilities across Europe has seen some marginal increase. There were 1,067 biomethane-producing facilities in total in Europe at the end of 2021.This represents an additional 184 plants compared to 2020, making 2021 the year with the biggest increase in biomethane plants. France overtook Germany in 2017 in terms of the number biomethane plants. France confirmed 151 new plants that came already in operation in 2021 with a further 112 plants by the end of September 2022. Recent trends show an

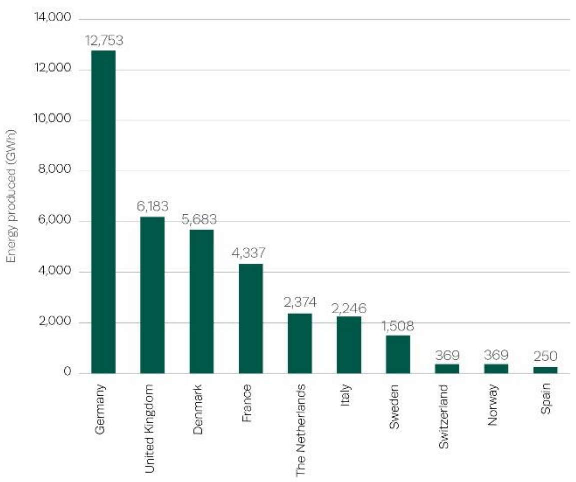

Figure 3 Biomethane production per country in descending order, (GWh), Top 10 countries

[5] https://energinet.dk/Gas/Biogas

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increasing share of smaller biomethane plants which highlights the feasibility of biomethane plants in all size ranges.

Generally, most countries have embraced biomethane production in the recent years. There are now biomethane plants operating in 22 European countries. Belgium (Flanders) and Estonia started biomethane production in 2018, followed by the Czech Republic opening its first two plants in 2019. In the course of 2020, Ireland, Latvia, and the Walloon part of Belgium also made their first injections of biomethane into the gas grid. Slovakia produced its first biomethane volumes in February 2022.

About three-quarters of the biomethane plants currently active use membrane separation (47%), water scrubbing (17%) or chemical scrubbing (12%) as their upgrading technology. The remaining plants use pressure swing adsorption (10%), physical scrubbing (2%) and cryogenic separation (1%). For 11% of European biomethane plants, no data concerning the upgrading technology is available.

Furthermore, biomethane can be transported either in the distribution grid or in the transport grid. Other plants too are stand-alone, without any connection to a grid. About 58% of the biomethane plants currently active in Europe are known to be connected to the distribution grid and 19% are known to be connected to the transport grid. 9% of European biomethane plants do not have a grid connection, and for the remaining 14% of Europe's plants no information is available to the EBA database.

Cross-border trade of Biomethane is largely facilitated by the European Renewable Gas Registry (ERGaR) through the certificate of Origin (CoO) since 2021. The scheme allows for cross-border title transfer (ownership transfer) of Certificates of Origin (CoO) between participating national biomethane registries. The scheme also streamlines the rules regarding the issuance of CoOs, as well as the protocol on the business processes for ownership transfers of CoOs between countries. Hydrocarbon gases, hydrogen and biomethane are included in the scope of the scheme, as well as other renewable gases that have been injected into the natural gas network.

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Chapter 3: Biomethane production routes in Europe

3.1 Anaerobic Digestion

Biogas is generally produced from the decomposition of organic materials in the absence of oxygen (anaerobic conditions). This process is mostly facilitated by a biodigester which controls all the conditions suitable for biogas production. A variety of feedstocks can be used as inputs for biogas production, such as sequential crops, animal by-products, industrial and commercial organic waste (Figure 1). These waste residues are placed in biodigesters where bacteria break the organic matter down releasing a blend of gases. These biodigesters provide the opportunity to regulate the conditions that effectively facilitates the production of biogas. The gas produced primarily contains 40 – 85 vol% methane and 25 - 50 vol% carbon [6]dioxide with few traces of other components. As a renewable energy source, biogas has multiple applications, the most common being the usage in a combined heat and power unit (CHP), which generates both heat and electricity.

The biogas can further be upgraded to produce biomethane**.** This consists of almost 100 vol% methane and has a quality equal to natural gas thanks to the removal of impurities such as CO_2, H_2O, H_2S from the biogas, leaving a high-caloric, pure gas. This gives biomethane various end-use applications such as biofuel for transport, injection in the natural gas grid, electricity and heat. For usage a biofuel for transport, biomethane is being further compressed to produce bio-CNG and bio-LNG.By- products of biogases and biomethane production are digestates and biogenic carbon dioxide.

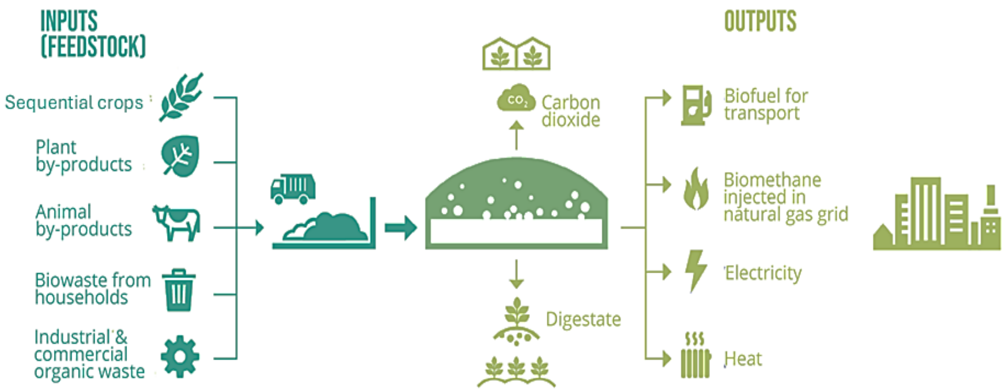

Figure 4 Schematic Overview of inputs and outputs of the biogas and biomethane production process

Biogas and biomethane are renewable gases which help abate emissions across the whole value chain. Their use is essential in accelerating the reduction of GHG emissions in multiple sectors,

[6] About biogas and biomethane | European Biogas Association

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including buildings, industry, transport, and agriculture. The sources of feedstock for producing biomethane and biogas makes it very a good option when it comes waste recycling, turning waste into valuable resources. Food waste or wastewater can be recovered to produce renewable energy which tends to also support local bioeconomy in most parts of Europe. Residues from animal farming or biomass are converted into energy, while digestates are produced and used as an organic fertilizer creating additional business models in the farming sector.

3.1.1 Biogas from Agriculture

Agricultural plants produce biogas mainly from agricultural waste streams. Crop residues, manure, leftovers from harvest, expired products, and as well as production errors from agricultural production are among the sample of feedstocks for a typical plant. Primarily, substrates are divided into two major categories at a biogas plants: a.) Those with no impurities and are not subject to animal by-product b.) Substrates which likely include impurities and are subject to animal by product regulation (1069/2011/EU)[7]

Feedstocks from Agricultural sources are mostly classified under category A except for manure. They can be stored in steadings and warehouses if dry, bulky, and not putrescent. Dry, not stackable, and not putrescent feedstocks are stored in non-gastight silos. While gas tight silos are used to store wet, bulky, and putrescent feedstocks that are likely to rot.

Depending on the feedstock characteristics; several mechanisms can be employed. Mostly commonly wheel loaders, conveyor belts, screw conveyors for solid agricultural feedstocks. While liquid substrates are delivered through pumps.[7] Upon delivery into the digestors agricultural feedstocks undergo either a wet or dry fermentation process based on the moisture content, physical or chemical characteristics. Wet digestion processes are carried out by continuously stirred tank reactors (CSTR). These reactors ensure a continuous flow of substrates which tends to avoid the formation of floating and sinking layers. This ensures constant biogas production in the digester and allows easy pump of digestates. This reactor system however allows only a limited percentage of dry matter content (Maximum of 15%).

3.1.2 Biogas from Sewage Sludge

Biogas from sewage sludge is produced mainly from municipal wastewater treatment plants. Effluents from households and municipal areas are subjected to a purification process. One of these steps involves the introduction of oxygen into the wastewater to facilitate reduction of the organic matter content by the bacteria in the sludge. The by-product settles below the tank, and it is separated from the purified water. The sludge is slowly pumped out of the tank and subjected to an anaerobic treatment to produce biogas. A common three-phase system used in wastewater treatment facilities for the treatment and reduction of BOD, COD, pathogens, and odor is the bio trickling filter and biofilm reactor. The sewage is separated into effluent and sludge. Methane is produced as a byproduct of the anaerobic sludge processing by mesophilic bacteria.

[7] DiBiCOO D2.2 Categorization of European Biogas technologies.

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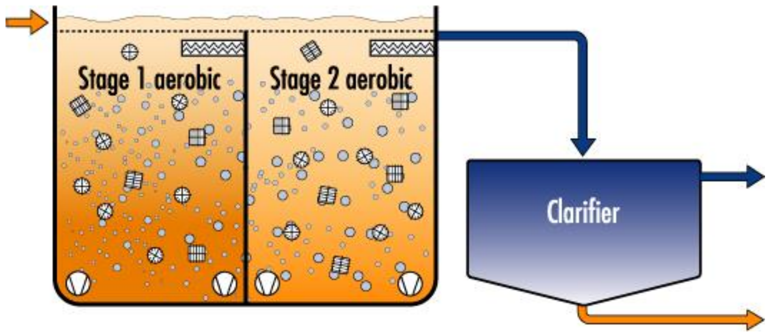

Figure 5 Biofilm reactor system. Image source: Lenntech

3.1.3 Biogas from Organic Municipal Solid Waste

Organic municipal solid waste (OMSW) from households and commercial building including food waste from supermarkets, and restaurants are the main components of the of Municipal solid waste systems. These are collected with waste bin and brought to processing plants to produce biogas. Due to their solid and sometimes dry nature, waste streams from OMSW are treated for biogas production using either anaerobic plug flow reactors (APFR) or silo fermenters. The plug flow reactor is a cylindrical, parabolic, and rectangular system specifically designed for dry fermentation. They require some pre-treatment of the feedstocks due to the incomplete mixing inside the reactor. The feedstocks are pushed through the reactor. The plug flow reactor is having relatively slow-moving parts compared to the CSTR. This makes it energy efficient with little wear and tear to the reactor system.

Silo Fermenters are based on the same principles of the plug flow reactor. The feedstocks are introduced at the top together with some digestates to serve as inoculum for bacteria decomposition. The difference with the fermenter is the absence of moving parts in the system. The feedstock moves through the reactor through gravity and digestate is retrieved from the bottom of the reactor.

3.1.4 Biogas Industrial Wastewater

Like wastewater from sewage sludge plants commercial and household sources, industrial solid wastewater are usually effluents from industrial plants, food and beverage companies, paper companies. But unlike the sewage sludge treatment which has an aerobic process before anaerobic treatment to produce biogas. The industrial wastewater is subjected to anaerobic treatment first. Reason being that aerobic treatment is energy intensive and expensive. Whereas effluents from industrial sources such as food processing plants are heavily loaded with organic content, hence it will be costly to undertake aerobic treatment. In this case, the anaerobic treatment is done first to produce biogas by the action of bacteria to reduce the organic content load before the aerobic process starts. During the anaerobic process, the UASB reactor is used in the purification process.

The reactor consists of a single tank containing granular anaerobic bacteria. The rising of the methane bubbles and the upward flow of the entering water combine to form these granules. Without using any mechanical assistance, the substance can be mixed in this flow direction.

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Slats to separate the water, gas, and sludge are located at the reactor's top. Sludge particles, biogas, and purified water are separated in the reactor's upper section. Because anaerobic bacteria perform best at temperatures between 35 and 38 degrees Celsius, this approach is especially appropriate for rather warm effluent.

3.1.5 Biogas from Industrial Solid Waste

The solid content from industrial waste such as food processing, pharmaceuticals, organic

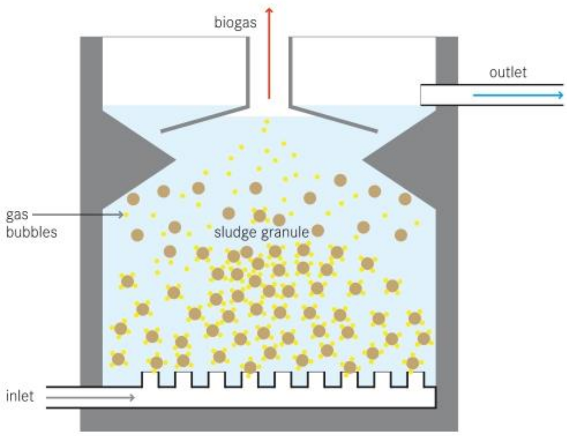

Figure 6 Upflow Anaerobic Reactor Sludge Blanket digestion, UASB

chemicals, paper manufacturing can also be processed for biogas production. Solid feedstocks from industrial waste can be co-digested with other feedstocks in a continuously stirred reactor tank. Due to the semi-solid nature of the feedstocks.

From an industrial standpoint, the method of producing biogas is heavily dependent on the feedstocks component of the industry. While cassava flour plants typically utilize UASB, High Suspension Solids-Up-Flow Anaerobic Sludge Blanket (H-UASB), Fixed Film, and anaerobic filter, producers of frozen food, canned food, and fruit juice typically use UASB, Covered Lagoon, and anaerobic filter systems. Plug flow digesters and UASB are typically used in slaughterhouses.

3.1.6 Landfill Gas.

Biogas from landfills is naturally produced continuously without much involvement or reactor processes. Organic component in waste stream decomposes over time by the action of bacteria to produce biogas. The production is higher for closed landfills compared to open landfills. Closed landfills provides a much conducive anaerobic environment for microorganisms to produce biogas. Landfill gas become inert with time and the biogas production reduces. The biogas produced by landfills can be hazardous if not checked and they can lead to explosion in landfills. To control this, Flame ionization detectors are installed to detect methane levels, coupled with surface and sub-surface monitoring. This is necessary especially in cases where the landfill needs to be reopened for landfill mining or land recovery and development. Biogas from landfills can be collected using several methods. The most common method is by gas extraction wells which collects biogas at different depths of the landfill and sends them up to gas header pipes for processing or upgrading.

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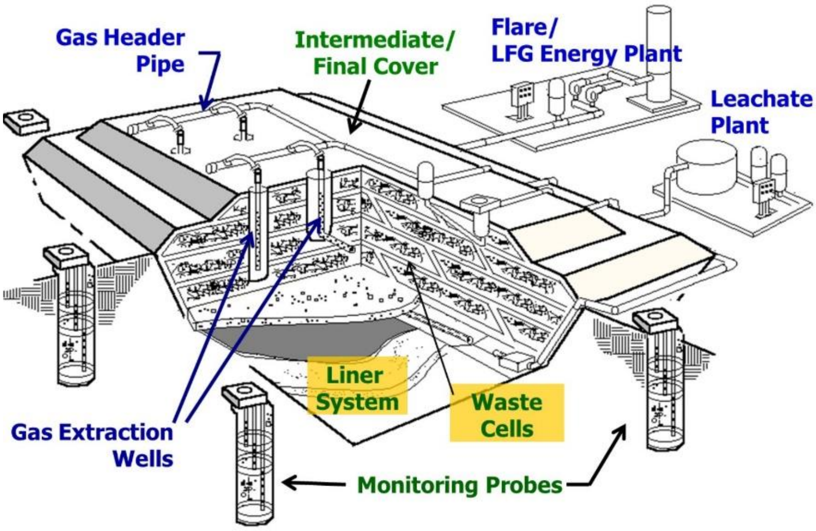

Figure 7 Landfill Gas Extraction Process

3.2 Gasification

Gasification is the process of producing gas from solid fuels. This method was adopted in the late 19th Century to provide gaseous fuels from coal or peat for domestic use. The direct burning of wood biomass in open fireplaces or wood boilers was a forerunner to the gasification of biomass and is possibly the earliest method of generating energy for cooking, heating, and lighting. For many years, it was done in open fireplaces or straightforward wood stoves, which were typically constructed by skilled local craftsmen.[8]

Overtime the process has advanced from a single air inlet to a staged combustion operation which usually includes a couple or more discrete combustion air inlets. A carefully constructed combustion chamber, and heat exchangers. This has significantly decreased emissions while also dramatically increasing efficiency of the system. It is also it is much more likely to attain combustion efficiencies above 100%. This is mostly on condition that heat exchangers are built to condense the vapor in the exhaust flow. In addition, compared to emissions from boilers manufactured in the 1980s, these innovations have reduced emissions of carbon monoxide and particulate matter by almost 90%.

The gasification process is an incomplete biomass combustion process that creates a calorific gas that can then be fully burned. It produces by-products such as charcoal, depending on the procedure employed. By reducing the oxygen input below the level necessary to fully burn all combustible substances, gasification can be accomplished. In an endothermic process, the energy needed to initiate the process is more than the energy that is directly released during the process.

This results in the process being completed in the absence of additional external energy. The energy needed to continue the process can be obtained either externally or by partially burning the feedstock or produced gas (autothermal) (allothermal) similar to steam or vapour. After gas cleaning, the generated gas will undergo full oxidation, which will result in the production of

[8] DibiCoo Deliverable D2.2, Categorization of European Gasification technology

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heat, steam, combined heat, and power (CHP), or even biomethane. Different kinds of gasification medium can be utilized for the partial oxidation of the wood biomass that occurs during the gasification process. Air is typically the gasification medium of choice, but other choices include oxygen or vapour. Various types of gasification techniques exist, with differences in size, feedstock, and gasifier medium. Some types of gasifiers technologies include:

- Fixed bed gasifier – Updraft, Downdraft
- Fluid bed gasifier – Standing fluidize bed, Circulating bed.
- Entrained flow gasifier

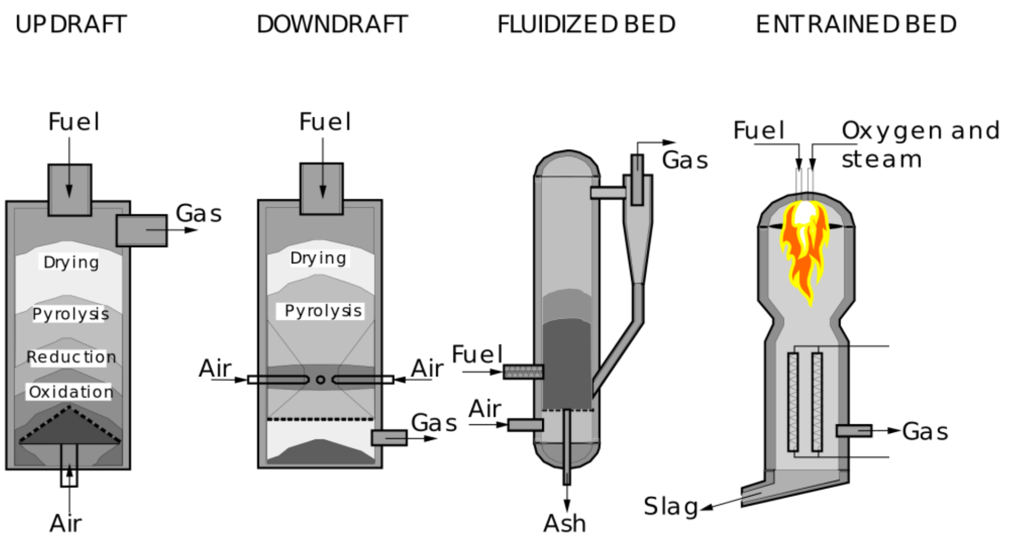

*Figure 8 Types of gasifiers, Image Source : [H2*4U*](#)*

Fixed Bed Gasifier – Updraft: In contrast, the gas in an updraft gasifier flows in the opposite direction from the biomass. The biomass right above the grate is usually the first thing the oxidant reacts with as it enters at the bottom. The gas produced at this point flows upward and undergoes reduction, Pyrolysis and then drying.

Fixed Bed Gasifier – Down Draft: The idea behind a fixed bed downdraft gasifier is that during the gasification process, wood chips and wood gas move in the same direction. Wood chips are heated and dried after entering the gasifier, then undergo pyrolysis at a temperature of more than 150 °C before the oxidant is introduced. The reaction heats up to about 1000 °C upon insertion of the oxidant, which is typically air. The final phase is a reduction one, which converts partially created tar or pyrolysis oil from the pyrolysis process into gaseous fuel.

Fluidized Bed Gasifier: The biomass is fed into a gasifier bed in a fluidized bed gasifier, where it comes into contact with the heated gasifier bed medium. The material used in the gasifier bed enables quick, intense gasification. Quartz sand or any other material with extra catalytic qualities, such as limestone, dolomite, etc., can be used as the material for the gasifier bed. The gasifier medium, typically air, oxygen, or vapor, lifts and suspends the gasifier bed material; to do this, the gasifier medium needs to be injected with the proper vector and velocity to lift and fluidize the bed material. This fluidization of the bed material increases the amount of feedstock contact and results in a significantly faster.[8]

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3.3 Biogas compositions

For any given sample of biogas produced, there main components are about 40 – 80 Vol % Methane and 25-50% Carbon Dioxide. Depending on the type of feedstocks used, the biogas produced may contain impurities such as hydrogen sulphide, siloxanes (silicon organic compounds), ammonia, oxygen, and water. These impurities are required to be removed during a pre-treatment process prior to further steps of biogas usage or upgrading to biomethane. Hydrogen sulphide (H_2S) for example is harmful to humans and equipment. It also oxides during combustion to form sulphur oxide (SO_2) and sulphuric acid (H_2SO_4) and corrodes parts of the biogas plants, pipes, and vents. The table below gives an overview of average composition of biogas based on a scientific study of plant types[9]. When unavailable the average composition in Vol% was calculated taking the average of the maximum and minimum values.

There are some factors that can affect biogas composition.

Table 1 Average Biogas composition based on plant types.

Biogas CH4/CO2 content

The CH_4 and CO_2 content in a given biogas depends mostly on the type of incoming substrate (e.g., carbohydrate- protein- or lipid-rich), digester operating conditions (temperature, pH, etc.) and the degree of air injection for in-situ H_2S oxidation.

Component (%Vol)	Type of Plant									
	Agricultural Plants		Sewage Plants		Industrial Plants		Organic MSW		Landfill	
	Range	**Avg**	**Range**	**Avg**	**Range**	**Avg**	**Range**	**Avg**	**Range**	**Avg**
CH_4 - Methane	49 - 69	56	56 - 65	60.5	57 - 67	62	44 - 63	53.5	40 - 70	53
CO_2 - Carbon Dioxide	29 - 44	39	38 - 40	39	32 - 41	36.5	32 -44	38	25 - 40	35
N_2 - Nitrogen	0.6 - 13	3	n/a	n/a	0.1 - 0.3	0.2	0.1 - 19	9.55	0 - 17	< 5
O_2 - Oxygen	0.2 - 3	0.6	0.1 – 0.4	0.1	0.1 - 0.2	0.15	0.1 - 2.9	1.5	0 - 3	< 1

Considering the H_2S content

The H_2S content depends mostly on the substrate type (organics composition) and sulfur content (inorganic - SO_4 and organic sulfur content), digester operating conditions and the injection of air or chemicals (e.g., iron) for in-situ H_2S oxidation. For example, industrial wastewater with a high sulfate content may generate biogas with up to 10 000 ppm H_2S, while in the case of low sulfate wastewater content the biogas H_2S will remain low (e.g., 200-300 ppm).

Biogas NH_3 content

[9] Adelaide Calbry-Muzyka, Hossein Madi, Florian Rüsch-Pfund, Marta Gandiglio, Serge Biollaz, Biogas composition from agricultural sources and organic fraction of municipal solid waste, Renewable Energy, Volume 181, 2022.

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Considering the biogas NH_3 content this depends mostly on the substrate type (e.g., protein-rich) and digester operating conditions (for example at high digester pH = 8.0, a portion of ammonia present in the liquid phase is transported-stripped to the gaseous phase-biogas). Moreover, digesters operating at high ammonia nitrogen concentrations in the liquid phase are thus more vulnerable to generate ammonia rich biogas.

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Chapter 4: Optimizing Feedstock Usages

4.1 Guideline for Optimizing efficiency of the feedstocks.

Optimizing feedstocks for a biogas plant involves finding the best combination of organic materials to use as a source of energy to produce biogas. There are several factors that should be considered when optimizing feedstocks for a biogas plant, including composition, nutrient content, availability and cost, seasonality, quality processing. It's important to note that the optimal feedstock combination will vary depending on the specific circumstances of each biogas plant, such as the location, size, and type of plant.

4.1.1 Composition

The composition of the feedstock will affect the biogas yield and the efficiency of the digestion process. Feedstocks with high levels of easily digestible carbohydrates, such as sugar and starch, will typically yield more biogas than feedstocks with high levels of cellulose and lignin.

4.1.2 Nutrient content

The nutrient content of the feedstock will affect the growth of the microorganisms that digest the feedstock. Feedstocks with high levels of nitrogen and phosphorus will typically support faster growth of the microorganisms and result in higher biogas yields.

4.1.3 Availability and cost

The availability and cost of the feedstock will affect the overall economic feasibility of the biogas plant. Feedstocks that are readily available and inexpensive will typically be more favourable than feedstocks that are scarce or expensive.

4.1.4 Seasonality

Some feedstocks may be available only in certain seasons, and this should be considered when selecting feedstocks for the biogas plant.

4.1.5 Quality

The quality of the feedstock may vary depending on the source, and this can affect the biogas yield and the efficiency of the digestion process. It is important to use feedstocks of consistent quality to ensure consistent biogas production.

4.1.6 Processing

Some feedstocks may require pre-treatment, such as grinding, before they can be used in the biogas plant. The cost of this pre-treatment should be taken into account when selecting feedstocks.

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4.2 Introduction to Mechanical and Pre-Treatment technologies

The type of feedstock used, the conveyance system, and the type of digester used dictate the amount and type of preprocessing. Preprocessing involves using storage to control the feeding of the digester. Preprocessing systems include, but are not limited to[10]:

- Separating fiber of dairy manure, if necessary.
- De-packaging food wastes.
- Reducing feedstock particle size.
- Screening non-volatile materials.
- Removing grit.
- Separating sand.

No single pretreatment technology is suitable for all anaerobic digestion systems and substrates. The choice of pretreatment method is strongly dependent on substrate composition, and the right combination of the right pretreatment technology and substrate composition is the key to increasing the bioavailability of the substrate.

The most important factors for selecting a pretreatment technology are the energy balance and costs. Pretreatments with low energy demand generally have a lower impact on the rate of degradation.

Pretreatment can be used to overcome some of the problems associated with lignocellulosic substrates, such as poorly accessible molecular structures, and emerging biogas substrates such as oil palm empty fruit bunches.

In lignocellulosic substrates, the main sources of methane are sugars and other small molecules. The breakdown of starch, cellulose and hemicellulose is complicated by the bonds between different cellulose chains and by the presence of lignin, another polymer that slows down the breakdown process. Different pretreatment methods can be assessed in different ways, from laboratory-scale experiments to trials at full-scale biogas plants. This is important because the equipment used for pretreatment at large scale is not the same as the equipment used for pretreatment at lab scale. The most informative test for pretreatment technologies is full-scale anaerobic digestion, but even at full scale there can be significant variation between different biogas plants.

Mechanical pretreatment is carried out by mills to reduce the particle size of the substrate, which increases the surface area available for enzymatic attack. This increases the rate of enzymatic degradation and reduces the problems of floating layers. Scientific literature divides mill into hammer or knife mills, depending on whether they grind or cut the substrate. However, many industrial-scale mills combine cutting and grinding, and are used in many biogas plants treating wastes.

[10] EPA, Anaerobic Digester/Biogas System Operator Guidebook, (2020), EPA 430-B-20-003. https://www.epa.gov/sites/default/files/2020-11/documents/agstar-operator-guidebook.pdf

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4.2.1 Knife mills and shredders

Knife mills or shredders cut or shred the substrate. Menind and Normak (2010) found that knife milling hay to 0.5 mm achieved a higher gas yield than 20 to 30 mm.

4.2.2 Hammer mills and other systems

Hammer mills have an energy demand of 2 to 5 times that of knife mills but are relatively easy and cheap to operate.

Menardo et al.[11] calculated that milling wheat and barley straw increased methane yield and that the energy used during milling was justified by the electricity saved by improved mixing.

4.2.3 Thermal pretreatment

Thermal pretreatment involves heating a substrate under pressure for up to one hour to disrupt the hydrogen bonds that hold together crystalline cellulose and the lignocellulose complexes. Thermal pretreatment is only effective up to a certain temperature, which varies with different substrates and is dependent on pretreatment retention time. Microwave pretreatment is possible for lignocellulosic substrates, but it is less effective than thermochemical pretreatment. Thermal pretreatment is particularly well suited to locations where there is a supply of waste heat, for example from a nearby factory or power plant. Chemical pretreatment has been investigated for biogas production but is not currently carried out at large scale.

4.2.4 Alkali pretreatment

Alkali treatment can increase gas yield from lignocellulose-rich substrates. However, the high salt concentration and resulting effect on the ammonium-ammonia balance inhibits methanisation during continuous fermentation.

4.2.5 Oxidative pretreatment

Oxidative pretreatment with hydrogen peroxide or ozone can increase biogas production from rice straw. However, introducing more oxygen into the system increases the proportion of CO2 in the biogas produced.

4.2.6 Steam explosion

Steam explosion makes substrates more digestible by combining heating and sudden pressure change. This causes intracellular water to evaporate very rapidly causing cells and their surrounding fibre to rupture. Bauer et al.[12] found that steam exploding straw increased biogas yield by 20%. One study has been done with continuous AD and steam-exploded straw. It found no significant difference between steam-exploded and untreated straw in terms of process

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[11] Menardo, Simona & Airoldi, G & Balsari, P. (2011). The effect of particle size and thermal pre-treatment on the methane yield of four agricultural by-products. Bioresource technology. 104. 708-14. 10.1016/j.biortech.2011.10.061.

[12] Bauer, Alexander, et al. "Analysis of methane potentials of steam-exploded wheat straw and estimation of energy yields of combined ethanol and methane production." Journal of Biotechnology 142.1 (2009): 50-55.

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stability and methane yields. Steam explosion pretreatment can decrease methane yield but allows new substrates like straw to be used for biogas production.

4.2.7 Extrusion

Extrusion is a process adapted from other industries such as the plastic-processing industry, where material is subjected to high shear, temperature, and pressure. It breaks open the cell structure of biomass, which results in faster methane production, which in turn facilitates higher organic loading rates. Hjorth et al. (2011) investigated the effect of extrusion on batch methane yield of straw, grass, manure, and deep litter from cattle. A major problem with extrusion pretreatment technology is that the screws must be changed after a few months due to abrasion.

4.2.8 Thermochemical pretreatment

Different kinds of bases and acids can be used in thermochemical pretreatment, but temperatures of more than 160 °C show a drop in methane production. Rafique et al. (2010) found that high concentrations of lime (5%) enhanced gas yield at 70 °C. Monlau et al. (2012) found that pretreatment with H2O2 or NaOH (4 g / 100 total solids) increased methane yield by about one third at 55 °C, and that pretreatment with HCl at 170 °C increased methane yield by around 20%. Silage making (ensiling) has limited effect on AD and is mainly carried out for storage reasons. It does not increase the rate of biogas production and is therefore not addressed further in this brochure.

4.2.9 Anaerobic microbial pretreatment

Anaerobic microbial pretreatment (pre-acidification) is a simple kind of pretreatment technology in which the first steps of AD (hydrolysis and acid production) are separated from methane production. Microbiological pretreatment can speed up the degradation rate of substrates in AD by creating an optimal environment for the degradation enzymes. A two-stage continuous AD system produces more methane than a single-stage continuous AD system when digesting grass silage. This is because the microorganisms of the first stage are less sensitive to many chemicals and can break down many inhibiting chemicals in the first stage.

At large scale, several biogas plant providers offer pre-acidification systems, varying from continuous to batch pre-acidification systems. Plug-flow reactors are also available and have the advantage of a specific retention time.

Two-stage digestion is useful for a range of different substrates, and the added stability of feeding with a constant pH helps to lower gas upgrading costs.

4.2.10 Aerobic microbial pretreatment

Aerobic microbial pretreatment can be carried out with naturally occurring mixed cultures. The microorganisms present break down chemicals that might otherwise inhibit methanogenesis in the anaerobic digester.

Mshandete et al. (2005) used aerobic pretreatment to treat sisal fibres and added sodium bicarbonate as a buffer to prevent acidification during pretreatment. Their batch tests showed that aerobic pretreatment increased methane yields 26%.

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A process similar to the anaerobic leach bed system described by Lehtomäki et al. (2008) and Nizami et al. (2011) can be used to pretreat municipal solid waste using an integrated aerobic-anaerobic pretreatment process.

The major advantage of leach bed reactors (aerobic or anaerobic) is that there are no processing problems due to fibres or large chunks in the anaerobic digester. The disadvantage is that the leach bed reactors need to be emptied and the solid fractions needs to be disposed of.

4.2.11 Fungal pretreatment

White-rot fungi have been used to remove pollutants from wastewater and coffee cherry husks before anaerobic digestion. This has led to more research on solid waste detoxification before anaerobic digestion.

Fungal pretreatment of straw with white-rot fungi has been investigated as a pretreatment for anaerobic digestion, but it is not clear what effect fungal pretreatment has on biogas yields.

4.2.12 Enzyme addition

Addition of enzymes can enhance the breakdown of biomass in anaerobic digesters, either by direct addition to the digester or by addition to the hydrolysis and acidification vessel of a two-stage system.

The addition of enzymes to anaerobic digestion has been analysed in many different studies. Some studies showed that the addition of enzymes to the first stage of a two-stage anaerobic digestion process leads to slightly higher substrate solubilisation (leading to higher biogas yield).

A study by a Swiss group looked at 25 different commercially available enzyme preparations and found that the effect of enzymatic pretreatment on biogas yield from sludge and manure was minimal.

4.2.13 Sanitation

Some substrates, such as animal by-products, require hygienisation or sterilisation before anaerobic digestion. Thermal pretreatment systems such as TDH can be used for these substrates.

4.2.14 Ultrasound treatment

Ultrasound treatment can be used to treat sewage sludge or the liquid effluent from anaerobic digesters, for example to aid solid-liquid separation. It causes the disruption of microbial cell walls, which sets hydrolytic enzymes free and helps to increase the hydrolysis rate of biomass.

4.2.15 Electrokinetic disintegration

Electric fields are used for a variety of processes in modern biotechnology, including sewage sludge treatment and pretreating substrates similar to sewage sludge. It is not clear what effect, if any, this treatment has on lignocellulosic material.

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4.2.16 Prospects for pretreatment technologies

Pretreatment of AD can increase rate of AD and gas yields, and reduce methane emissions from the digestate, leading to reduced greenhouse gas emissions.

Many pretreatment methods are expensive or have a high energy demand, and their efficiency is often difficult to prove. However, some pretreatment methods can stabilise biogas plants and make new substrates available for anaerobic digestion.

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Chapter 5: End-uses of Biomethane

5.1 Technological Options

Once the biogas has been produced and then purified to yield biomethane, a range of options are available for its end-use, although it is worth to note the final selection will be driven by the prevailing regulatory and incentive frameworks, as well as the infrastructure available nearby the biomethane plant. Biogas that has been purified and upgraded to biomethane can meet the same quality standards as natural gas.

There are several technological options for using biomethane as an energy source, including transport, building, industry and power.

5.1.1 Injection into the natural gas grid

Biomethane can be injected directly into the existing natural gas grid, which is used for heating, cooking, and electricity generation. The biomethane can be used interchangeably with fossil natural gas, reducing greenhouse gas emissions from the natural gas sector.

While the equipment cost for biomethane injection in the grid does not generally pose a major obstacle to the implementation of the system and is practically the same regardless of the distance between the biomethane plant and the natural gas grid connection point, the cost for piping and civil work for grid connection reflect the large variability of situations one might encounter, from river or railroad crossing, to burial and rehabilitation of land, with authors reporting variabilities in the range 55-1000 USD/m in 2014[13].

5.1.2 BIO-CNG and BIO-LNG

Biomethane can be used either in the form of Bio-CNG or Bio-LNG to serve as a transport fuel. Bio-CNG is the compressed form of biomethane and similarly, Bio-LNG is the liquified form of biomethane. Bio-CNG and Bio-LNG can replace conventional CNG and LNG derived from natural gas without any need for infrastructure changes. Both fuels can be produced either directly at the biomethane production plant (so called on-site production) or by extracting biomethane from the grid using Guarantees of Origin (GOs). When produced on-site, the Bio-CNG or Bio-LNG can be delivered to a filling station where it will be used as a transport fuel, or it can be transported via truck to be delivered to its final end-users. On-site production of Bio-CNG and Bio-LNG production is especially of interest in rural areas, where it can provide a green fuel at relatively low cost and without the need for transport via the gas grid.

Bio-LNG has a higher energy density than Bio-CNG, making it particularly effective as a sustainable fuel for heavy-duty and maritime transport. Recent studies show that Bio-CNG and Bio-LNG are the best performing fuels for decarbonising transport, outperforming even electric vehicles under certain conditions, thanks to their potential to offer a negative carbon footprint.

[13] Ong, Matthew D., Robert B. Williams, and Stephen R. Kaffka. "Comparative assessment of technology options for biogas clean-up." *California Biomass Collaborative* (2014).

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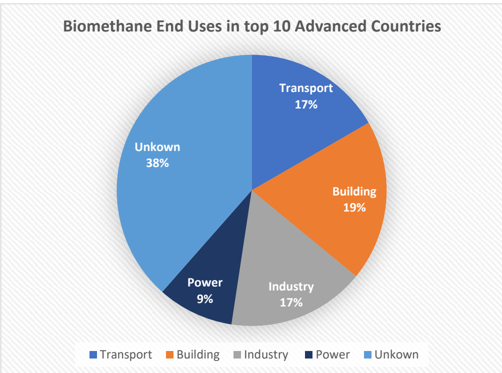
5.2 End-Use Sectors

As mentioned in the previous section , Biomethane has a variety of end uses applications:

- **Transport:** Biomethane can be used as a low-carbon fuel for transportat, particularly in the form of compressed natural gas (bio-CNG) or liquified natural gas (bio-LNG) for example, for heavy-duty vehicles such as buses and trucks.
- **Buildings**: Biomethane can also be used to generate heat and electricity through cogeneration systems, which produce both electricity and heat simultaneously. This is particularly useful for industries or buildings that require both electricity and heat, such as hospitals or industrial processes.
- **Industry**: Biomethane can be used industrial processes for the production of heat and running large machineries.
- **Power:** Biomethane can also be used directly as a fuel in some applications, such as in gas turbines or in fuel cells to generate electricity.

The specific end use of biomethane in Europe can vary depending on factors such as local infrastructure, regulatory frameworks, and market demand. The versatility of biomethane as a low-carbon fuel source thus makes it a valuable contributor to Europe's efforts to decarbonize its energy sector.



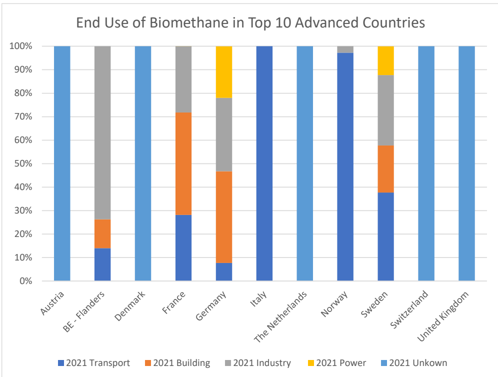


Figure 9 Category of Biomethane End Uses for top 10 advanced countries.

From the perspective of the EU, the transport sector uses a bigger proportion of the biomethane produced; countries like Estonia and Italy are well known for this. Also, this is a widespread trend in most European countries. In Sweden, the transportation sector receives the majority of the biomethane produced in the form of Bio-LNG and CNG, followed by industry and buildings. We will consider the final utilization in Italy and Germany for the benefit of this project.

Germany:

In total, 10,667 GWh of biomethane were produced in Germany in 2021. The typical biomethane utilization pathways include use in CHP units, heat and transportation sectors as well as the exports. Biomethane produced in plants receiving EEG tariffs is mainly utilized in CHP processes with a share of 80 % in 2021. Under the EEG regime in about 1,200 biomethane CHP-

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units 3,133 GWh electricity were generated, while 4,977 GWh of biomethane was utilized for heating and cooling in 2021.

While industry used an additional 3,988 GWh. A little more than 1,000 GWh, or 8% of the total production of biomethane in 2021, was used as transportation fuel. In comparison, the amount of biomethane used for transportation in 2017 was 445 GWh, followed by 389 GWh in 2018, 660 GWh in 2019, and 884 GWh in 2020. The Federal Pollution Control Act encourages the use of biomethane in transportation in Germany by requiring fuel firms to lessen their carbon footprint. The creation of Bio-LNG is of great relevance. Germany is anticipated to overtake Italy and the Netherlands as the region that produces the most bio-LNG in Europe. In fact, Germany is home to the largest plant now under construction in Europe, with a production capacity of approximately 1,500 GWh/year. Around 7 % of biomethane were utilized in the heat sector. Here, the utilization of biomethane is motivated among others by the in 2021 introduced CO2 pricing as stated within the Fuel Emissions Trading Law from 2019, which makes energy from biomass indirectly more competitive in comparison to fossil fuels. Further, the Buildings Energy Act is an additional instrument promoting the increasing energy performance of the buildings as well as the use of renewable energies for heating and cooling provision, foreseeing a review of the energy performance requirements for new constructions and buildings in 2023.

Italy:

On the other hand, Italy is likely to meet its goal of 1.1 bcm of biomethane production annually by the end of 2023. This will soon replace all fossil natural gas in its transportation sector with biomethane, making it the first country in the world to do so. Italy has the largest fleet of natural gas vehicles in Europe with a total of 2,246 GWh was used in the transport sector alone. There are 126 LNG filling stations and 1,542 CNG filling stations. It is worth noting in Italy, only the production of advanced biomethane specifically for use in the transport sector is qualified for aid. Information regarding other end uses is yet to be known.

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Chapter 6: Best practices for biomethane supportive policies

This Chapter will present **successful policies for the development of biomethane markets identified in 10 "advanced countries" in the decade 2011-2021**[14]. This identification will serve as input to the analysis of market dynamics and framework conditions in the target countries of the Project.

The 10 "advanced countries" were the leading European countries for biomethane production in 2020[15]: *Austria, Denmark, France, Germany, Italy, the Netherlands, Norway, Sweden and the United Kingdom* (see Annex 1, Graph 1). They represented 96% of the European biomethane production in 2021. The leading countries combined enjoyed a growth rate of 624% biomethane production from 2011 to 2021 while there was little or no production in other European countries. Starting points and growth pace are, however, different among these countries; three market profiles can thus be distinguished:

- *Biomethane forerunners: Germany and Sweden*. They are countries that experienced an early emergence of biomethane production, i.e. before 2011-2014, compared to others (see Annex 1, Graph 3). They respectively accounted for 83% and 15% of European biomethane production in 2011.
- *Soaring biomethane markets*: *Denmark, France, Italy, the Netherlands, and the United Kingdom*. They emerged during the period 2011-2021 and grew very quickly within a few years. Different starting and take-off years can be observed (see Annex 1, Graph 2 and Graph 4)[16]: 2013 as a take-off year for the Netherlands, 2014 for the U.K., 2015 for Denmark, 2016 for France, and 2017 for Italy. Over a period of 5 years from 2017 to 2021, their production grew of 50% or more (Denmark +292%, France + 968%, Italy + 651%, the Netherlands +119% and the United Kingdom +50%)
- *Slow-growth markets*: *Austria, Switzerland, and Norway*. While their biomethane production experienced a marked increase during the decade, their average yearly increase rate from their respective take-off year until 2021 was under 50% and their production was still under 1 TWh in 2021.

The period 2011-2021 was deemed as the relevant timeframe to observe the emergence and upward evolution of biomethane production in these 10 countries while including their different starting points; it was also considered as a period long enough to observe the impact of policies on the market. However, measures taken before 2011 were also considered as their impact triggered the start of biomethane markets in some countries[17].

[14] "Policies" here refers to adopted laws and governmental decisions of either strategic, legislative, regulatory or technical level.
[15] Year of the writing of the project proposal.
[16] We consider as a take-off year the year when 1) the production had substantial growth compared to the previous two years; 2) there was at least a 50% increase compared to the previous year; 3) the production outreaches 100 GWh/year, while being following by significant growths in the years afterwards.
[17] Results may not be comprehensive.

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The results are based on, on one hand, analyses of available documents and reports, including from past EU-funded projects[18], and, on the other hand, questionnaires filled in by national biogas associations or other representative stakeholders[19].

Policies addressing biomethane were broken down into five categories:

1. National vision;
2. Direct investment and production support;
3. Indirect production support;
4. Demand-side incentives;
5. Regulations enabling market access.

6.1 Vision and Targets

This section identifies measures setting a vision for the development of the national biomethane sector. A vision is a useful framework for planning public policy measures and for the industry players to plan their investment. It provides the following benefits:

- Long-term policy perspectives to the value chain; and
- Understanding of biomethane role within the energy, agricultural and waste management systems (what role should have biomethane production and uses, what are their most valued benefits or externalities);

For these reasons, a national vision is often long asked for by the industry. It can be laid out or sketched through different, possibly combined, means:

- *A formal governmental strategy, plan or roadmap for biogas and biomethane*. It can take the form of a stand-alone document or of a section within a more general official document (such as a renewable energy strategy, the National Energy and Climate Plan (NECP)[20], or a landmark official speech of a Minister).
- *Target setting*: official targets on production or consumption; they can be indicative or binding; political or legal; short-term or long-term targets. Official binding consumption targets anchored into national legislation are seen as strong driver for the development of the sector. Alternatively, indications of the government-attributed role for biomethane can be found in energy production or consumption forecasts. These may be found in national plans, such as the NECP.
- Targets may be underpinned by *a government-mandated assessment of biogas and biomethane production potential*. Alternatively, a government can create a dialogue with the biogas industry that can lead to a recognition or an endorsement of an existing industry-led assessment.

[18] Regatrace (2019-2022): https://www.regatrace.eu/ ; Biosurf (2015-2018), see https://www.europeanbiogas.eu/project/biosurf/ ; Green Gas Grids (2011-2014): see https://www.dena.de/en/topics-projects/projects/renewable-energies/greengasgrids-green-gas-for-europe/.

[19] In the case of information about Denmark.

[20] NECPs are required by Regulation 2018/1999 on Governance of the Energy Union. They are available online: https://energy.ec.europa.eu/topics/energy-strategy/national-energy-and-climate-plans-necps_en .

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6.1.1 Good practices from the 10 advanced countries

❖ ***Vision***

From 2008 to 2021, Danish authorities progressively laid out a vision of the role of biogas and biomethane, through political initiatives and regulatory decisions affecting all renewable energies, until adopting a dedicated "Green Gas Strategy" in 2021.

- From the 1980's, "*Denmark started the promotion of biogas production based on clearly identified positive benefits such as decreasing nitrogenous gases from the agricultural sector (livestock), energy dependency and producing heat for neighboring communities*"[22].
- In 2009, biogas was publicly considered as a way to recycle manure and reduce methane emissions and produce green energy in the "*Green growth initiative*". The document stated an "*objective that 50% of the livestock manure is to be used for green energy in 2020*". The focus was on production of raw biogas through farm-based anaerobic digestion; nutrient recycling and GHG emission mitigation was the main rationale behind it. Biogas would be used through on-site combined heat and power generation (CHP).
- In 2012, the Energy Agreement extended the vision of energy production from anaerobic digestion to biomethane and its injection in existing gas grids, as a new support scheme was set up for this production pathway.
- In 2019, the Danish NECP included a forecast of energy equivalent of biogas and biomethane consumption towards 2030, recognizing these energies as significant for the renewable energy targets for 2030.
- In May 2020, the Danish government published "*Powering Denmark's Green Transition*, "*a roadmap developed by energy corporations and the Danish government*."[21] It lays out a clear vision on the end-uses of biomethane in industry, district heating, housing, heavy transport and power generation. For instance, biomethane is set to replace coal and natural gas in industries and natural gas in 30% of gas-fired boilers.

Italy set a national vision for biomethane through the National Recovery and Resilience Plan (NRRP). The support scheme approved by the European Commission in August 2022 had been prepared and notified already in 2021. It recognizes the quality of biomethane as versatile high energy density fuel that can be used in both transport and heat production. "*As part of its strategy, Italy seeks to improve the reconversion and efficiency of existing agricultural biogas plants towards partial or total biomethane production as well as the development of new plants. Accordingly, key end-use sectors include the industrial, residential heating and cooling, and transport sectors with encouragement to expand biomethane usage to other sectors ensuring demand aligns with 2026 production potentials*"[22]. The Italian Recovery Plan aims at a biomethane production of c. 4 to 5.5 bcm (42-58 TWh) in 2030.

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[21] Gas for Climate, *Market state and trends in renewable and low-carbon gases in Europe* (2021). See also: https://www.danskenergi.dk/files/media/dokumenter/2020-07/Powering_Denmarks_Green_Transition_Climatepartnership.pdf

[22] Gas for Climate, *Manual for national biomethane strategies* (2022).

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Norway included an "Action plan for biogas" in its Climate Plan for 2021-2030, adopted by the Government's Cabinet in January 2021. It highlights the GHG emission reduction potential in agriculture and transport. It references the production potential study made by the Norwegian Environment Agency in 2020[23]. It outlines existing and possible future support measures to achieve this potential.

❖ ***Production potential assessment***

Setting a national long-term vision for biomethane requires a consensual understanding of the production potential, quantity and feedstock-wise. Assessment performed by national energies agencies of Austria and France contributed to move in this direction.

- In France, the French Energy and Environment Agency (ADEME) published in 2018 the study "*A 100% renewable gas mix in 2050?*", performed jointly with gas network operators GRDF and GRTgaz[24].
- In 2020, the study "*Renewable Gas in 2040*" was performed by the Austrian Energy Agency, Energy Institute of Johannes Keppler University and EVT Leoben, and was supported by the Austrian Ministry for Climate Protection[25].

❖ ***Official targets (see Annexes 2 and 3)***

In 2019, the Austrian government included a **forecast figure** in their National Energy and Climate Plans (NECPs):

13 PJ in 2030, equivalent to c. 3,6 TWh.

NECPs were required to be finalised by end of 2019 pursuant to the Governance Regulation adopted in 2018. NECPs are a tool for the European Commission to monitor the ambition, targets and policy measures to ensure that the collective contribution of the Member States deliver on the EU-wide energy and climate targets for 2030. It is therefore significant that a national administration includes clear forecast figure in their NECPs.

France set **a binding renewable gas target** through a law ("*Loi de Transition Energétique pour la Croissance Verte*") adopted in 2015: 10% of renewable gas consumption in 2030. The long-term climate strategy adopted in July 2017 ("*Stratégie Nationale Bas-Carbone*") started giving a long-term vision on the share of renewable gas in the energy system (200-250 TWh in 2050). This was a positive signal for industry players (especially the biogas sector and the gas network operators), to draft strategies, plan investments and advocate in favour of biomethane production.

[23] It estimated the potential in 2030 at 2.5 TWh/year. However the Norwegian biogas industry assessed the potential to be 10 TWh/year.

[24] Source: https://librairie.ademe.fr/energies-renouvelables-reseaux-et-stockage/1548-mix-de-gaz-100-renouvelable-en-2050--9791029710476.html

[25] Source: https://www.bmk.gv.at/themen/energie/publikationen/erneuerbares-gas-2040.html

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Austria, Denmark and the Netherlands adopted **official political renewable gas targets**.

- A target of 5 TWh/year of 2030 was announced by the Austrian government in 2018 and confirmed in a governmental agreement of 2020. While Austrian governments have been more focused on renewable hydrogen production than biogas and biomethane, this measure opened the door to discussing with national authorities the contribution of the biomethane industry to this target.
- In the Netherlands, the governmental "Climate Agreement" of June 2019 planned to realise 70 PJ/y (19.44 TWh/y) of "green gases" in 2030, equal to 5.4% of the total gas demand in 2017. This objective was confirmed in the "Green Gas Roadmap" of 2020.
- The Danish Energy Agency published an official "Green Gas Strategy" in December 2021. The document sets the objective of 100% renewable gas consumption in 2035.

The French government adopts regular 7-year "Multiannual Energy Programs" (MEP) ("*Programmation Pluriannuelle de l'Energie*") defining priorities of action and **indicative targets**. The MEP of 2019 foresaw a production of subsidized biomethane of 8 TWh in 2023 and of 24-32 TWh in 2028. On the top of this, 3,8 to 6,1 TWh of energy from biogas-based cogeneration was also targeted for 2028. These decisions reinforced the momentum of the biomethane industry. However, the MEP of 2020 revised downwards the 2023 and 2028 targets to, respectively, 6 and 14-22 TWh.

In May 2020, a joint industry-government roadmap included **an indicative target** of 13,3 TWh/year biomethane in 2030 ("*Powering Denmark's Green Transition*", May 2020). This was later confirmed by in the "*Green Gas Strategy*" published in December 2021 by the Danish Energy Agency.

6.2 Direct investment and production support

Direct support is granted directly to biomethane producers, most often related only to the energy production of the plant. *Direct investment support* means covering capital expenses such as the building of the production facilities or the grid connection. *Direct production support* is a pro rata payment per amount of biomethane produced and/or per amount of electricity from on-site biomethane combustion. Three types can be identified:

- Feed-In Tariffs (FiT): payment of a fixed price is guaranteed for each output unit and for a defined period;
- Feed-In Premiums (FiP): payment of a variable top up equal to the difference between the market value of the output and a predefined price;
- Contracts for Difference: top up payment in the same way as a variable Feed-In Premiums but with the obligation for the beneficiary to make a payback if market prices go above the predefined price level.

Feed-In Tariffs can be granted through two different systems:

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- Open access to all plants, with possibly different levels of tariffs depending on the plant capacity. Compliance with sustainability rules is a precondition[26].
- A tender system through auctions: The state pre-defines volumes of subsidy by auction. During an auction, different levels of Feed-In Tariffs are offered to plants project with the lowest projected cost of production. Different tenders can be made by the state for different ranges of plant capacity.

Direct production support provides certainty to project developers and investors about the profitability and the return on investment. It is considered also as a prerequisite to reach a critical mass of a national industrial players able to achieve economy of scale in plant building and equipment manufacturing. Overtime, economy of scale on both the manufacturing and biomethane production side deliver cost reduction.

6.2.1 Good practices from the 10 advanced countries

A guaranteed feed-in tariff was implemented in Denmark (2012-2019), France (2011-2020) and the U.K. (2011-2021). In all three countries, it was instrumental in the production take-off in the following 3-4 years.

- . In France, between 2011 and November 2020 a base tariff was granted for 15 years based on maximum production capacity of plants and feedstock types. On the top of this, plants processing municipal waste, agricultural and agro-food waste and sewage sludge received premium payments. In 2016, a ceiling of 15% (annual gross weight) was set on the use of food and feed crops as main crops. Thus a waste-based sustainable feedstock supply was incentivised.
- Danish support was a combination of a Feed-in Tariff and a Feed-in Premium: a base subsidy was guaranteed for 20 years to all applicants on top of a variable premium based on the average natural gas price of the previous year. A cap of 12% energy crops (measured in weight) was set as an eligibility requirement. The cost of production and upgrading had to be reported against the subsidy received to avoid breaching EU rules on overcompensation. From 2012 the support scheme triggered a shift of interest from biogas to biomethane injected in gas grid, especially from large producers and groups of farmers.

From 2004 to 2017, the German biomethane sector benefitted from an open-access **feed-in tariff for the electricity produced from biomethane** . An "upgrading bonus" was implemented from 2009-2014 to give biomethane advantage compared to biogas[27]. The FiT thus fostered new production capacities over this period. Since 2017, the feed-in tariff has been granted through tenders[28].

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[26] Feed-in Tariffs are considered as State Aids and as such are regulated by EU's state aids rules, specifically the climate, environmental protection and energy Guidelines (the 'EEAG' and since January 2022, the 'CEEAG').
[27] EYL-MAZZEGA M.-A., MATHIEU C. (eds.), « Biogas and biomethane in Europe: Lessons from Denmark, Germany and Italy », *Etudes de l'IFRI* (2019).
[28] Tenders should contribute to an annual indicative growth targets for "sustainable biomass" (which include biogas and biomethane).

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The Netherlands has implemented **a feed-in premium** for injected biomethane since 2011 while keeping a FiP for electricity generated from biogas. The FiP makes up for the difference between natural gas price and biomethane costs; its level is linked to the feedstock used[29] and the reported greenhouse gas emission reduction. The subsidies are granted through a tender system. This system thus incentivises the use of sustainable feedstocks while keeping public spending in check.

Between 2014 and 2021, the State Agency Enova has pledged a total of about €39 million (NOK 430 million) for the building of biogas and biomethane production plants. The support is based on innovation and cost efficiency per energy unit produced. The size of investment support may vary depending on the project.

6.3 Indirect production support

Indirect support to production refers to incentives, on one hand, to provide feedstock to biomethane producers, and, on the other hand, to produce further products on top of biomethane (on-site flexible electricity generation, digestate (as organiser fertilizer) and biogenic CO_2 (as an industrial gas)). Indirect support located upstream can be of two types:

- *Regulatory incentives* for feedstock providers to direct their organic waste/residues towards anaerobic digestion, e.g., sectoral target of waste disposal reduction or methane emission reduction, end of landfilling with no energy utilization of organic waste.
- *Financial incentives* to do so, e.g., payment for farmers to deliver manure to biogas and biomethane producers.

The inclusion of indirect support mechanisms indicates that policymakers recognise the benefits of anaerobic digestion beyond energy production. Anaerobic digestion is supported because of the benefits it provides for upstream feedstock-providers such as livestock farming (e.g., better nutrient recycling through digestate production), municipal waste (e.g., local circular energy production for municipalities), food and beverage industries (e.g., reduced GHG footprint). Indirect support mechanisms are therefore a way to reward economically the positive externalities of biomethane production. They also increase the overall competitiveness of biomethane production.

6.3.1 Good practices from the 10 advanced countries

The Swedish government launched in 1999 the quality assurance scheme "Certified recycling" ("*Certifierad återvinning*") to build trust among users of organic fertilisers, including digestate from anaerobic digestion. In 2016, 99% of digestate produced in co-digestion plants (most of them using food waste from households as substrate) was used on agricultural lands[30]. This certificate scheme was a technical enabler for marketing digestate successfully on the national market and thus securing an additional revenue stream.

[29] In 2020, the premium was between €30/MWh (sewage treatment plant) and €79/MWh (biomass gasification).

[30] Source: European Biogas Association.

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Since 2013 farmers receives subsidies per ton of manure supplied to biogas production. The measure aims to tackle methane emissions from manure. The agricultural agreement 2020–2021 raised the program to NOK 9 million (€797,000 million) in 2021 against NOK 5 million (€455,000) in 2020.

In Germany, the feed-in tariff for renewable electricity from biomethane has also applied since 2004 to central power and CHP plants . It valued the seasonal storage capacity of gas infrastructure into which biomethane is injected.

Since 2009, a subsidy program supports the digestion of slurry and manure. It proved successful from 2009 to 2015 to utilise increasing volumes of livestock effluents for biogas and biomethane production.

6.4 Demand-side incentives

This set of measures stimulates the consumption of biomethane (hence the term "consumption support")[31] in two ways:

- Increasing the competitiveness of biomethane through tax incentives;
- Framing biomethane into an obligation.

Tax incentives can be tax reduction (on excise duty or VAT) compared to standard taxation of fossil fuels or natural gas; or tax exemption (on excise duty or carbon taxes). Toll reduction or exemption for gas-driven vehicles also belongs to this category.

When framed into an obligation, biomethane is valued as one of the options to comply with:

a. An obligation of a renewable energy share (usually motor fuel suppliers are the obligated party);
b. An obligation of an advanced biofuel shares by motor fuel suppliers;
c. An obligation to reduce its GHG emissions, possibly as part of an emission trading system;
d. Public procurement's rules on the types of equipment or fuels that a public authority can procure.

Demand-side incentives generally raise awareness for the actual product and improve consumers' perception of it. Tax incentives create immediate financial interest compared to use of conventional fuels; they can therefore trigger a quick growth of biomethane consumption. They are instrumental in creating a market in specific end-use segments.

Demand-side incentives can also encourage biomethane production by creating certainty of the future demand, thus the profitability of new plants.

6.4.1 Good practices from the 10 advanced countries

❖ ***Quota and obligation mechanisms***

The United Kingdom launched in 2008 the Renewable Transport Fuel Obligation. Road fuel suppliers had to reach a share of 13.078% of renewable fuel in their supply mix by 2023. Biomethane from waste counts double in meeting the target. While drop-in biofuels in petroleum fuels accounts for most of this effort, biomethane's share emerged significantly between 2018 and 2021, from 0,5% to

[31] Investment support for gas-driven equipment (CNG or LNG vehicles, CHP systems) was not investigated.

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4,4% of total renewable fuels. Combined with a lower excise duty than petroleum fuels, this measure drove the interest in gas-driven vehicles.

Between 2018 and 2022, Italy implemented an obligation of biofuels and advanced biofuels. Fuel suppliers had to reach a 9% share of biofuels[32] and 1.85% of advanced biofuels in their supply mix. In 2020, the advanced biofuel quota was raised to 3% in 2023, of which 2.25 had to be "advanced biomethane". In addition, the "Biomethane Decree" of 2018 set an official and binding target of 1.1 bcm of biomethane consumed in the transport sector by the end of 2022. These measures were the greatest push for biomethane production in the 2018-2022 period.

Germany pushed for increasing use of renewable energies in the transport sector through a GHG reduction obligation and integration of the sector in the national ETS.

Electricity, biomethane and hydrogen are treated equally in public procurement policies. As a result, the use of biomethane in public transport and in public procurement of transport services (e.g., captive fleets of public authorities) is expanding.

❖ ***Tax incentives***

In Germany, purchase of biomethane for CHP is tax exempted. A tax reduction is also applied for heat generation only. In tax reduction for biomethane as a motor fuel was also applied from 2019 to end of 2023.

In Sweden, biomethane was exempted from carbon and excise duty from 2011 to 2023 for transport and heat production (including CHP). Natural gas as a motor fuel was exempted from carbon tax only. These measures sustained a strong move towards gas and biomethane in heavy duty transport, coaches and buses, so much so that more than 95% of gaseous fuels in transport is actually biomethane.

In Norway there has been *full tax exemption for biomethane as a motor fuel* for several years. From 1 July 2020, liquid biofuels on the road are taxed, which may increase the incentive to use biomethane.

In Switzerland, waste-based biomethane is *exempted from carbon tax and mineral oil tax* which has been the main driver for its use in transport. Fuel suppliers have to prove its renewable origin with certificates of origin.

In the Netherlands, use of liquefied biomethane (bio-LNG) was incentivised from 2014 to 2021 by a partial exemption on the excise duty, as a way to curb GHG emissions from the transport sector. A partial switch to LNG-fuelled lorries was observed country-wide as a result.

Heavy-duty vehicles using fully biomethane are exempted from toll at intercity highways. Combined with tax exemption, this amounts to a significant driver for haulage companies.

[32] Compared to the total quantity of petrol and diesel released for consumption.

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6.5 Regulation enabling market access

Market access for biomethane refers to both access to existing gas networks and market recognition of its renewable origin and its compliance with sustainability requirements.

Biomethane as a gaseous fuel is most often injected in existing gas networks. Making this access possible, simple and affordable for project developers is therefore integral to a profitable business case of biomethane projects, thus to the development of a biomethane market[33]. Measures enabling injection include:

- A right to inject, including the obligation for grid operators to address requests for grid connection;
- Clear and achievable gas quality specifications for biomethane;
- Cost-sharing of the investment with grid operators;
- Continuity of injection ensured all-year round no matter the initial grid capacity.

Tradability of biomethane as a renewable fuel depends on the creation of a system guaranteeing the renewable origin of energy quantity produced by plant operators. In the past 12 years, it could have taken the form of:

- A government-mandated issuing body and registry of Guarantees of Origin pursuant to the Renewable Energy Directive 2018/2001;
- Alternatively an industry-initiated green certificate registry, where the certificates will be recognised by the market, including energy suppliers, as proof of renewable origin.

6.5.1 Good practices from the 10 advanced countries

❖ ***Injection in gas networks***

Denmark, France and Germany were forerunners in creating a "right to injection" for project developers and all cases this was an enabler of sharp growth of biomethane production.

- Denmark created in 2013 a right to inject and a framework for contractual relation between grid operators and producers. This, in combination with the production support scheme and the voluntary green certificate scheme, created a shift in interest from biogas to biomethane production. However, the investment cost of grid connection, have remained fully borne by project producers. .
- In France, injection in gas grids was authorised as of 2011. In 2018, a law granted a right to inject to producers located outside areas served by distribution grids.
- In Germany, network operators are obliged to check the feasibility and preferentially connect biomethane plants if this is economical and technical reasonable. Biomethane has preferential access compared with domestic natural gas production and import.

[33] The alternative is to liquefy biomethane on-site and distribute by road transport. This is practiced in areas with no pre-existing gas networks.

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Regulation of grid connection CAPEX in France and Germany seeks to achieve a threefold goal: incentivizing grid connection, reducing plant operators' expenses and encouraging plant operators to locate their assets closer to the grid.

- In France, network operators can pay up to 40% of the investment of a connection since 2019 (up to 60% since March 2022) up to €600,000. In addition, a mechanism has been set up in 2019 to avoid the practice of "first arrived, first paying" for the others in case of a grid connection that will be shared in the future with one or several other plants.

- In Germany, the TSO bears the full investment in grid connection to its network, as well as in the injection station. When the plant gets connected to the distribution grid, costs are shared with the DSO: for pipelines up to 1 km, the producer shall pay max. €250,000. For pipelines ≥ 1 < 10km, the producer should pay 25% of CAPEX; for pipelines of ≥ 10km, the full cost is borne by the producer. In all these cases, the injection station is paid by the DSOs.

Denmark and Germany require network operators to build the necessary infrastructure to accommodate increasing biomethane injection. Infrastructure can include network meshing between municipal grids, but also reverse flow facilities that send gas back to a higher compression network (i.e., high compression distribution pipelines or the transmission networks). Costs are recovered through the tariffs. In 2021, 15 reverse flow facilities were operational in Denmark, France, Germany, and the Netherlands, with 25 under construction in Denmark, France, and Belgium[34].

The same measures have been implemented in France since 2020 but through a forward-looking approach that ensures cost-effective choices and facilitates project development.

- Based on the mapped biomethane production potential and the pipeline of projects, grid operators were tasked to anticipate and map *a)* what will be the best connection plan for future plants *b)* what type of grid reinforcement will be needed and where to accommodate all injected biomethane. The exercise is done per small area.
- The maps are available publicly developers can rely on it to assess the feasibility of projects.
- If a production project is set to trigger a grid reinforcement in the future, the producer will have to pay a fee/MWh produced.
- When an investment need arises, grid operators have to set up a plan in line with the mapping exercise and with technical-economic criteria set by the Regulator.

Within 18 months, the mapping exercise already covered 44% of homeland France. It identified needs for grid reinforcements that would enable and secure continuous injection of 35 TWh biomethane a year[35].

[34] Gas for Climate, *Market state and trends in renewable and low-carbon gases in Europe* (2021).
[35] Commission de Régulation de l'Energie (CRE), *Bilan de la Mise en Œuvre du Droit à l'injection du Biomethane dans les Réseaux de Gaz* (2021).

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❖ *Trade based on certificates or Guarantees of Origin*

In France and the Netherlands, a government-mandated issuing body and registry for Guarantees of Origin were set-up before the adoption of the new Renewable Energy Directive 2018/2001:

- In France, gas DSO GRDF was mandated in 2012. Within 6 years (2012-2018), most production was associated with Guarantees of Origin; 28 energy suppliers had registered to procure biomethane.
- In the Netherlands, registering and certifying biomethane production has been mandatory since 2015.

This enabled the emergence of green gas offers by energy suppliers and at refilling stations.

Alternatively, in Austria, Denmark, Germany and the U.K., the industry successfully led the creation of voluntary green gas certificate registries. These registries established connection between one another through bilateral agreements. These agreements are being replaced by the ERGaR's Certificate of Origin scheme set up in 2011 to facilitate cross-border title transfer of certificates of origin[36].

- Austrian balance group coordinator (AGCS) has operated a registry since 2012. It issues "biomethane certificates" as a basis for the biomethane-based renewable power Feed-in Tariff. Traders can register and procure certificates. The expertise and the IT system developed by AGCS is recognised as a replicable example in Europe[37].
- British Green Gas Certificate Scheme (GGCS) was set up in 2011 and issues certificate proving the renewable origin of the gas procured and supplied to consumers. In 2021, it got listed as an Approved Certification Scheme for compliance with the UK green gas levy.
- In Germany, DENA's biogas registry, established in 2010, issues GO and other certificate of origin since 2010.
- Energinet (Danish gas transmission network operator) set up a biomethane certificate scheme before the implementation of the RED II. Biomethane's green value was thus recognised very early in the emergence of this new market[38]. Energinet entered into bilateral agreements with other issuing bodies in Europe, for instance with DENA's biogas registry in 2017[39], which created new marketing opportunities for producers.

[36] See ERGaR, ERGAR CoO Scheme, https://www.ergar.org/ergar-coo-scheme/.
[37] See REGATRACE, *Report D3.2*.
[38] Energinet now operates a government-mandated registry of Guarantees of Origin based on the Renewable Energy Directive 2018/2001.
[39] Energinet, "Denmark sells biomethane certificates to Germany" (2017), see link. Energinet is now in the process of joining the ERGaR CoO Scheme replacing bilateral agreements.

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6.6 Conclusion

Based on the experience and success in the 10 advanced countries, the following conclusions can be made:

1. Governments should set out a long-term vision for the biomethane sector's development, identifying the benefits of biomethane production and usages that the State intends to leverage and maximise and how it relates to other policy areas (agriculture, transport, housing). It can be in the form of dedicated "Action Plan" or within their National Energy and Climate Plans. Consensus among political forces is best in order to ensure continuity through successive governments and facilitate social acceptance among institutions and citizens.
2. Clear political or legal targets on production or final consumption contributes to this vision. When a major role is foreseen for renewable hydrogen in the future gas mix, a renewable gas target is not enough and a clear target for biomethane should at least be decided by the government or the legislators.
3. Feed-in tariff and Feed-in Premium are the most effective means to launch a market in the first years, if the levels of support are carefully designed considering the investment capacity of potential project developers, plant size and feedstock types. The target capacity of the support scheme should be clearly communicated to the industry, with a time horizon of at least 5 years.
4. FiT and FiP can be very effective if a right to inject into gas grids as well as the "renewable value" of biomethane are already recognised. The right to inject should be set into law and implemented swiftly by the government. The market recognition of the renewable value is achieved by setting-up a voluntary registry of Certificate of Origin or by a government-mandated registry of Guarantees of Origin pursuant to the Renewable Energy Directive 2018/2001.
5. A cost-sharing mechanism for grid connection can be a major financial support to new biomethane plants, especially for small to medium-sized project developers who cannot afford the full investment cost. Level of costs borne by network operators can be regulated by law, decrees and decisions of the national regulatory authority.
6. Integration with agricultural policy is essential to improve profitability of biomethane plants, which also produces digestate and biogenic CO2. This can be done by removing technical barriers to digestate marketing in the fertilizer market and/or subsidising the utilisation of manure in biomethane production.
7. Target of advanced biofuels and biomethane, as well as tax exemption or reduction are effective market signals to spur demand growth in transport. A combination of tax advantage for natural gas and full tax exemption for biomethane can be very effective to create a diesel-to-gas switch in road freight and public fleets, as the quantity of biomethane is progressively increasing and replacing the use of natural gas in this sector.

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However, these 10 advanced countries have also failed to address permitting/licensing, an area where no significant good practice was reported. Long processes are a major barrier identified by the industry EU-wide[40]. The Common Agricultural Policy could also be a financing tool to develop anaerobic digestion plants for the purpose of producing renewable energy and organic fertilizer based on agriculture; but it was hardly used in the 10 countries[41].

Since February 2022 and the Russian invasion of Ukraine, EU Member States have been working on stepping up renewable energy development to increase their security of supply while achieving their climate mitigation objectives. Ramping up rapidly biomethane production has become a strategic need for the European Union, as recognised by the REPowerEU Communication of 8 March 2022[42] and by the REPowerEU Action Plan of 22 May 2022[43]. The European Commission's REPowerEU plan includes an indicative target of 35 billion cubic meters (371 TWh) of domestic biomethane production per year in 2030, a twelve-fold increase compared to 2021 level. The REPowerEU Plan also outlines measures that Member States should take. The Biomethane Industrial Partnership set up in Autumn 2022 offers a space for government officials and industry stakeholders to discuss solutions to barriers to production expansion[44].

Against this backdrop, national policy landscape is expected to change very quickly, and new good practices could be identified within two years. It will therefore be important to track which steps these 10 advanced countries take to unlock further their biomethane production potential and sustain it on the long-term.

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[40] The European Biogas Association highlighted this in its recommendation for the REPowerEU Plan. Suggested actions include establishing one-stop shops, regulated review times and transparent communication to actors requesting permits. See: EBA, *Short-, mid- and long-term strategies to speed up biomethane deployment in Europe* (2022), https://www.europeanbiogas.eu/wp-content/uploads/2022/06/Short-mid-and-long-term-strategies-to-speed-up-biomethane-deployment-in-Europe.pdf

[41] Based on the investigation, only Austria included biogas and biomethane production and the organic fertilizer derived from it in its CAP schemes.

[42] European Commission, *Communication COM(2022) 108 final*, 08/03/2022.

[43] European Commission, *Communication COM(2022) 230 final*, 18/05/2022.

[44] See: https://bip-europe.eu/

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Chapter 7: Biomethane Market – Country Analysis

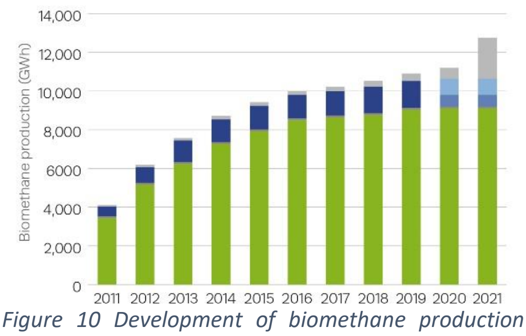
7.1 Germany

In Germany with 31.3 TWhe produced, biogas incl. biomethane amounted to 13.4 % of the electricity generation from renewable energy sources (RES) in 2021. The heat supply from biogas and biomethane accounted for about 17.9 TWht in 2021, which corresponds to 9 % of the energy supply provided by RES resp. to around 1.5 % of the end energy consumption in the heat sector (BMWK, 2022).

At the end of 2021, 8,600 plants with on-site electricity generation from biogas as well as 244 units upgrading biogas to biomethane were in operation. The basic biogas production including biomethane can be amounted to 10 billion m3 resp. more than 100 TWh HHV[45] per year. The feed-in capacity of the biomethane plants accounted for 149,035 m3STP[46] h-1 with the feed-in of 10 TWh HHV of biomethane (DBFZ, 2022; dena, 2021).

Today's biogas production in Germany comprises about 10 % of the total natural gas demand in Germany, with about 1 billion m3 biomethane (resp. 10 TWh HHV) 1 % is already produced. With regard to the existing biogas plants (with on-site electricity generation) DBFZ estimates, that taking into account the current situation and price increases, about 20 to 50 % of the existing biogas plants could be retrofitted to provide biomethane in the medium term (approx. 20 - 50 TWh HHV). By tapping the still unused agricultural residue potential (straw, catch crops, doubling the use of farm manure), the volume of the raw gas could be increased to around 20 % of the current natural gas consumption in Germany without additional energy crop cultivation.

The following figures provide an overview of the development of biogas upgrading units and the respective feed-in capacities from 2006 till 2021. In the period from 2014 to 2021, mainly medium-capacity biogas upgrading plants (350 to 700 m3STP h-1) have been installed, while the number of smaller (< 350 m3STP h-1) and larger (> 700 m3STP h-1) biogas upgrading units has increased only moderately.



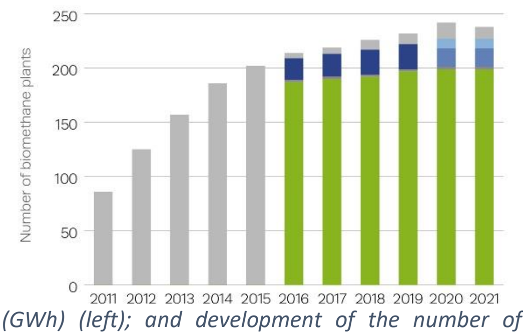


Figure 10 Development of biomethane production (GWh) (left); and development of the number of biomethane plants (right) Source: EBA Statistical report.

[45] HHV = high heating value

[46] STP = standard temperature and pressure (the normal state at 0º C and 1013.25 mbar)

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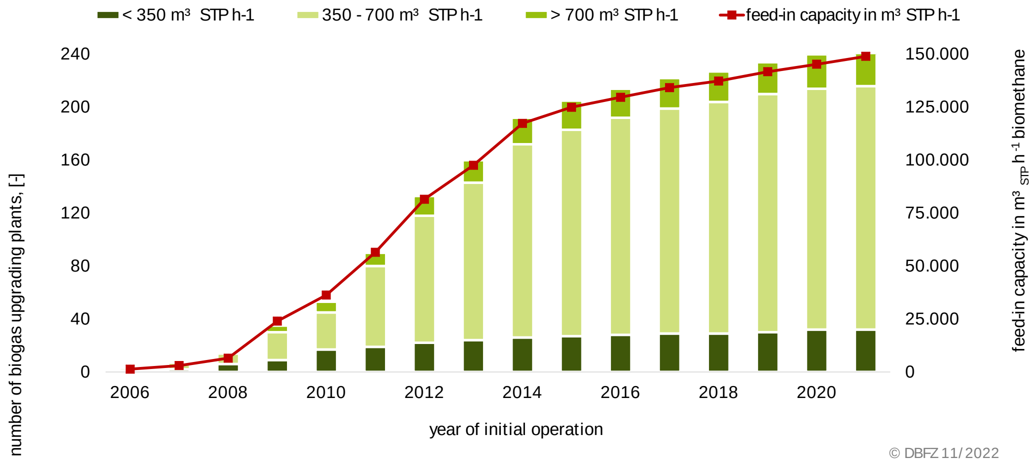

Figure 11 Number of bioas upgrading plants in Germany

Due to the agricultural infrastructure in Germany, the highest upgrading capacities are installed in the eastern part of the country, specifically in the federal states Saxony-Anhalt (21.5 %), Brandenburg (14.5 %) and Mecklenburg-Western Pomerania (11.9 %) (DBFZ, 2022).

Consequently, there is a higher feed-in of biomethane in Eastern Germany due to the large. farms located in the east in the regions with a high share of arable land and therefore higher available biomass potentials for biomethane production, whereas the higher demand for biomethane (biomethane-based CHPs) can be identified in Western

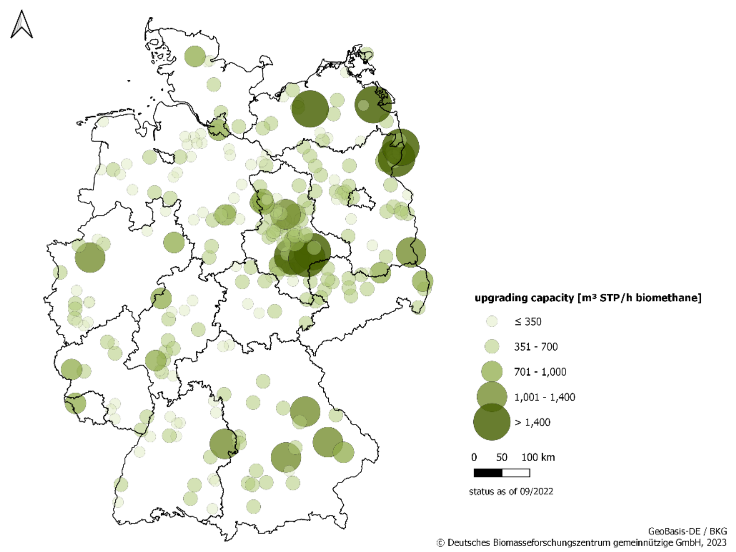

Figure 12 Biomehtane upgrading Capacity in Germany. Source DBFZ

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Germany due to the higher population density among others (cf. figure). Location of the operating biogas upgrading and feed-in units in Germany as of 9/2022 (source: biomethane data base DBFZ)

To upgrade biogas to biomethane, a separation of water vapour, hydrogen sulfide and carbon dioxide is needed. Thereby, the major challenge is the removal of carbon dioxide. In the last years, different processes have been established to upgrade biogas to biomethane. Since 2006, the predominant technologies in Germany have been water scrubbing, chemical scrubbing, and pressure swing adsorption (PSA). Occasionally, upgrading by physical absorption with organic solvents has been used. In comparison to preceding years, membrane separation upgrading technologies have been utilized increasingly and their distribution is now comparable to the upgrading units with organic physical scrubber (cf. figure).

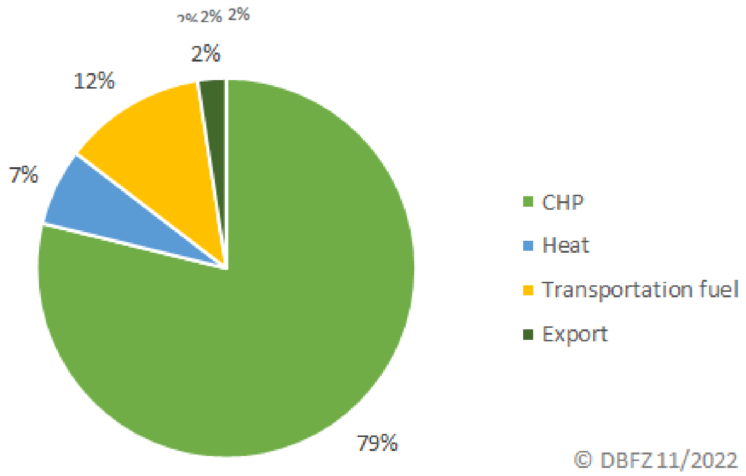

Figure 13 Market shares of technologies to upgrade biomethane in Germany in 2021 (DBFZ, 2022)

The typical biomethane utilization pathways include use in CHP units, heat and transportation sectors as well as the exports. Biomethane produced in plants receiving EEG tariffs is mainly utilized in CHP processes with a share of 79 % in 2021 (cf. Figure - dena 2022). Until 2019

Figure 14 Utilization pathways of biomehtane in Germany in 2021 (Dena, 2023)

biomethane as a fuel played a minor role compared to the other utilization pathways, but its share is currently increasing – from 389 GWh in 2018 up to 965 GWh in 2021 (BMWK, 2022). Thus, with 12 % it represented the second largest sales market, whereas the heat sector amounted to 7 % in 2021.

Under the EEG regime biomethane is used to generate heat and power in CHP units due to the focus of EEG on electricity generation. In 2021, the number of biomethane CHP units amounted to around 1,200 with the overall installed electrical capacity of around 654 MWe (cf. Table), where 3,133 GWh electricity and 4,527 GWh heat were generated (Netztransparenz, 2022a; Netztransparenz, 2022b; BMWK, 2022).

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Installed electrical capacity [kW_e]	Number of CHP units [n]	Total installed electrical capacity [MW_e]
≤ 75	262	8
76 - 150	144	19
151 - 300	210	50
301 - 500	167	66
501 - 750	154	92
751 – 1,000	79	68
> 1,000	188	351
Total	**1,204**	**654**

Table 2 Electricity capacity from biomethane CHP Units

Support Schemes:

At the European level, multiple regulations shape the development of renewable energies, thereby the national deployment of biogas resp. biomethane sector is especially influenced by the legal norms transposed into the national law or by the exclusive jurisdiction at the member state level.

Being adopted in July 2021, the **Renewable Energy Directive (RED II)** intended the increase from 32 % to 40 % as the RE target in the EU. In the transport sector renewable energy in road and rail transport have to amount to at least 14 % by 2030. The Renewable Energy Directive is transposed in Germany via a GHG quota by Article 37a–h of the Act on the Prevention of Harmful Effects on the Environment Caused by Air Pollution, Noise, Vibration and Similar Phenomena (Federal Immission Control Act (Bundes-Immissionsschutzgesetz BIMSCHG)). As in the RED II, there is a sub-quota for advanced biofuels from biogenic raw materials or feedstocks defined for this purpose, in addition to the overarching target.

The fulfillment of the specified quotas is linked to further framework conditions in terms of the limiting or multiple counting of individual options. For advanced biofuels (e.g. biomethane from liquid manure or straw) in road transport a double counting for amounts over the minimum percentage for energy applies. Conventional biofuels (e.g. biomethane from grain or other food crops) can supply with a maximum percentage for energy of 4.4 %.

Generally, distributors of gaseous biogenic fuels can only have these fuels counted towards the quota if they can prove that they meet the sustainability criteria required under the Biofuels Sustainability Ordinance (Ordinance on the Requirements for a Sustainable Production of Biofuels (Biokrafstoff-Nachhaltigkeitsverordnung) (Biokraft-NachV (2009)). (Naumann et al. 2023) The impact of the German GHG quota on biomethane in the transport sector is subject to considerable uncertainty. Due to the fact that the options within the quota are directly opposed, displacing and competing with each other, only biomethane with high CO2 savings can be included in the quota with certainty.

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On the other hand, advanced biomethane is certain to be used in the transport sector because of the sub-quota and is likely to be sold there because of the relatively high payment through the quota. The lack of infrastructure and gas-powered vehicles has a limiting effect. In the absence of a separate incentive, only the biomethane that can be purchased by the limited gas-powered fleet can be included in the quota. The new Proposal as of May 2022 contains the pledge for the rise of the RE target up to 45 % in the light of the changing energy market, increased prices, and the need to phase-out Russian energy imports.

The amendment of the **Renewable Energy Directive (RED III)** is currently subject of the trilogue negotiations. It also includes a target for the transport sector to increase the share of sustainable advanced biofuels to 0.5 % in 2025 and 2.2 % in 2030 (compared to 1.75 % without double counting in the current version of the RED II). The specific GHG reductions for the fulfillment options will be calculated for biofuels and biogas by multiplying the quantity of these fuels by the calculated emission savings (having different typical regional values for the cultivation of the raw materials is no longer possible).

Energy Taxation Directive (ETD) (2003/96/EC) shapes common framework for energy taxation at the EU level, thus providing the groundwork in order to reach climate policy goals. Became effective in 2003, it defined structural rules and minimum duty rates for the taxation of energy (electricity, motor, and heating fuels). The **Energy Duty Act in Germany** (Energiesteuergesetz, ENERGIESTG) transposes the requirements of the ETD at a national level and regulates the taxation of fossil and renewable energy carriers. The use of biofuels is indirectly affected by the current preferential treatment of fossil gas fuels, such as CNG, LNG and liquified petroleum gas (LPG), as well as their biogenic substitutes, like biomethane. A reduced tax rate will apply to gaseous hydrocarbons until December 31, 2026 and to non-blended liquefied gases until December 31, 2022 in accordance with Section 2: Tax Schedule, Paragraphs 1 and 2 (EnergieStG (2006)). However, tax rates are continuously increasing; for gaseous hydrocarbons they will rise from 13.90 EUR/MWh (until 2023) to 27.33 EUR/MWh (2026).

Starting January 1, 2027, the regular tax rate of 31.80 EUR/MWh will apply. For liquefied gases, the reduced rate of 363.94 EUR/t in 2022 will be replaced by a regular tax rate of 409 EUR/t from 2023 onwards. The corresponding Ordinance for the Implementation of the Energy Duty Act (Energy Duty Implementation Ordinance (Energiesteuerverordnung, ENERGIESTV)) regulates details on the implementation of the Energy Duty Act (EnergieStV (2006)). (Naumann et al. 2023)) In recent years, tax incentives have helped gas-powered vehicles to gain a little ground in Germany, but they cannot compensate for the general differences in vehicle costs and the lack of infrastructure. Additional infrastructure improvements would be needed to support the consumption benefits. The withdrawal and slow phasing-out of the tax incentive in its current form further reduces the impact.

ETD becomes outdated though without reflecting first and foremost the EU's commitment of at least 55% reduction in greenhouse gas emissions by 2030. For this reason, as a part of "Fit for 55" package, a new revision proposal of the Directive was introduced in 2021 consisting of two-tier amendment. In accordance with that, a new structure of tax rates referring to the energy content and environmental performance of the fuels and electricity rather than to volume was set up as well as the taxable base was broaded by considering more products and by removing some of the current tax exemptions and reductions. The new tax rates are now based on the actual energy content and environmental performance of fuels and electricity in euros per gigajoule:

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- 10.75 EUR/GJ for conventional fossil fuels as well as non-sustainable biofuels,
- 7.17 EUR/GJ for natural gas, LPG and non-renewable fuels of non-biological origin (for a transitional period of ten years),
- 0.15 EUR/GJ for advanced sustainable biogas; for ten years, this tariff also applies to low-carbon hydrogen and related fuels (e.g., ammonia, bio-LNG).

As a result, by the new categorization the most polluting fuels will be taxed the highest and the removed national exemptions will result in lower margins for the member states, which will make electricity and heat from fossil fuels more expensive and thus biomethane indirectly more competitive (European Commission, 2021). If introduced as proposed, this would have the potential to continue to favor gas-powered vehicles for 10 years. However, a German deviation from the implementation of the European minimum requirements could have a limiting effect. Furthermore, infrastructure would probably need to be incentivized as before.

The European Union Emissions Trading System (EU ETS), currently within the fourth trading phase (2021-2030), applies to the EEA-EFTA[47] countries and is about limiting the emissions in the power sector, energy-intensive industries, and the airlines operating between EEA-EFTA states. Fuels from advanced biomass (RED II Annex IX) are to receive the lowest tax rate among all energy sources, sustainable biomass at least a reduced rate. As a part of "Fit for 55" package, a revision of EU ETS in 2021 was envisaged by the European Commission. Within the agreed version, EU ETS should provide a set of the measures in order to lower the emissions in the EU by at least 62 % referring to the 2005 levels by 2030. The road transport and heat sector but also manufacturing should become part of the new emissions trade to become effective in 2027 after two-year implementation period.

Thereby contrary to EU ETS I, due to the missing zero-priced certificate allocation incentives for fuel savings resp. indirect competitive advantage for biomethane are provided by increasing the price of fossil alternatives, thus opting for low-emission technologies. However, in case of higher energy prices EU ETS II can be postponed until 2028 (European Parliament, 2022; UBA, 2021). Further, air transport sector should be amended and involvement of the maritime transport from 2024 on should provide an extension of the ETS application areas as well.

The **Clean Vehicle Directive (CVD)** encourages the further use of low-emission and zero-emission vehicles in public tenders (Directive (EU) 2019/1161 (2019)). The directive applies to passenger cars, vans, trucks and buses when acquired through purchase, lease, rental or rent-to-own contracts in accordance with the obligations of EU procurement regulations. The directive defines a "clean vehicle" as follows:

- Clean light commercial vehicles: any car or van that meets the following emission limits:
- Until December 31, 2025: no more than 50 g/km CO2 and up to 80 % of the applicable limits for real driving emissions (RDE) for nitrogen oxide and particle count,
- From January 1, 2026, onwards: only zero-emission vehicles.
- Clean heavy commercial vehicles: any truck or bus that uses e.g. natural gas (both compressed natural gas [CNG] and liquified natural gas [LNG], including biomethane)

The impact depends on the limiting factors and affects only a limited number of vehicles. In addition, the focus is probably only secondarily on gas-powered vehicles.

[47] EEA = European Economic Area comprise EU member states and three EFTA (European Free Trade Association) states Iceland, Liechtenstein, and Norway

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According to the *Act on Levying of Route-related Charges for the Use of Federal Highways and Federal Roads* (Bundesfernstraßenmautgesetz (**BFStrMG**)), medium and heavy commercial vehicles must pay a toll for the use of certain roads.

This applies to vehicles or vehicle combinations that are intended or used to transport goods by road and whose maximum permissible weight is 7.5 metric tons or more. One exception is for vehicles powered by natural gas, which only have to pay partial toll rates to cover infrastructure costs (0.08 to 0.174 EUR/km) and to cover noise pollution costs (0.002 EUR/km). The partial toll rate to cover air pollution costs of 0.011 to 0.085 EUR/km is waived. (Naumann et al. 2023) The beneficial effects are likely to have a minor effect, which is outweighed by other consumption-related costs, especially with the current gas price.

REPowerEU plan (A plan to rapidly reduce dependence on Russian fossil fuels and fast forward the green transition) represents formally a non-binding strategy document released in May 2022 aiming for ending the EU's dependence on Russian fossil fuels and tackling the climate crisis. The main aspects include:

- Increased energy savings (raising target from 9 to 13 % of the EU Energy Efficiency Directive in light of the “Fit for 55” package);
- Diversification of energy imports into the EU (liquefied natural gas);
- Substitution of fossil energy through the accelerated expansion of power generation capacities from wind and PV, hydrogen (generation and import), and biomethane.

It proposes changes, e.g., to the RED (increase the 2030 target for RE from 40 % to 45 % under the “Fit for 55” package) and the doubling of biomethane production by 2030, aiming to achieve a target of at least 35 billion m3 (350 TWh) of an annual biomethane production by 2030 as a part of the Biomethane Action Plan, among others through the incentives under the Common Agricultural Policy (CAP). In order to do so, more biogas must be produced and existing biogas converted to biomethane with the need for more incentives to build up new plants and provide biomethane by repowering existing plants in the EU (European Commission, 2022).

At the national level, pivotal for the development of electricity from renewable energies in Germany and biogas resp. biomethane plants in particular was the Renewable Energy Sources Act (EEG). It initially entered into force in 2000 playing a key role in the success of the German energy transition (so called “Energiewende”). Since then, there was a series of the law amendments in 2004, 2009, 2012, 2014 and 2017. The most recent version of EEG became effective in 2021 and the new one is expected to enter into force in 2023. The three pillars of the EEG consist of (i) the right of grid connection for renewable energy facilities, (ii) the obligation for net operators to preferentially purchase electricity based on renewables and (iii) a minimum feed-in-tariff/ awarded auction value to be paid for the generated electricity.

The major driver for the expansion of biomethane in Germany were the ambitious goals of the German government and, more specifically, the introduction of the bonus for biogas upgrading within the amendment of the EEG in 2009. A lower upgrading limit of 700 m3STP/h for biomethane plants to be built was introduced by the biogas upgrading bonus within the EEG 2012 making smaller upgrading capacities uneconomical. The annual growth rates were further substantially reduced after the abolishment of the biogas upgrading bonus in 2014. For biogas plants with on-site conversion, the significant increase in number and installed electric capacity was motivated by the specific substrate bonuses within the EEG 2004 and 2009 resulting in a

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veritable biogas boom between 2009 and 2011, whereas the most recent amendments led to a significant reduction of the feed-in-tariffs and, which is more important, in the abolishment of substrate bonus for energy crops.

Against the backdrop of the amended legal framework conditions since 2012, the extension of capacity in the biogas sector has mainly comprised plant expansions, adjustments for a flexible plant operation as well as a slight extension of small manure-based biogas plants and plants for biowaste digestion. In addition, the introduction of the market and flexibility premium in the EEG 2012 set course for future requirements in the bioenergy sector.

The amendment of EEG in 2017 laid down the shift from feed-in tariff (FiT) model from the previous EEG versions 2000 – 2014 to the tenders for renewable energies. The main political arguments for this switch are the cost reduction, the need to favour market integration and the establishment of the competitive renewables as well as the (limited) biomass potentials. The auctions are based on a pay-as-bid model with one annual auction round from 2017 till 2019 as well as two auction rounds per year introduced in 2019. The biogas plants to be built with an installed electrical capacity of more than 150 kWe till 20 MWe as well as already existing biogas facilities can participate in auctions. Since the implementation of tendering model, 10 auction rounds have run so far. However, the auctioned volume for biomass in all ten rounds was not completely used resulting in the missing costs reduction.

The reason for that are compliance requirements (both technical and bureaucratic) and, what is more important, the actual costs of biogas plants installations and operations that cannot be covered by the ceilings on the bidding values. Besides, there is also costs competition among biomass and other renewables such as wind and solar power – within the latest auction round the value for existing biomass plants was 18.22 ct/kWhe resp. 16.24 ct/kWhe for biogas plants to be built compared to 5.88 ct/kWhe for onshore wind and 5.9 ct/kWhe for solar in 2022 as the highest (Bundesnetzagentur, 2022a; Bundesnetzagentur, 2022b; Bundesnetzagentur, 2022c). However, the cost competition of and the revenues from biomass plants have changed due to the rising energy prices as a consequence of the Russian invasion in the Ukraine.

From 2021 on, separate auctions were established for biomethane CHP units (1,300 h runtime per year resp. 15 % of rated power) initially in Southern Germany (so called “southern quota”). Whereas within the first round in December 2021 the total auctioned volume of 150 MWe was completely exploited, during the second round in October 2022 only 2 biddings with the total volume of 3.5 MWe were auctioned. The possible reason for that is the benchmark with the current gas prices, whereas the maximum bidding value for biomethane within the second auction round in October 2022 amounted to 18.81 ct/kWhe (Bundesnetzagentur, 2022d).

The introduction of specific growth targets for different technologies was and is a new development for the German renewables support scheme. According to the EEG 2021 installed electrical capacity of biomass plants is set as 8,400 MWe in 2030. Further adjustments of EEG 2021 include the rising up of the installed capacity of small-scale manure-based plants from max. 75 up to 150 kWe, the increase of the bidding values for existing biomass plants up to 18.4 ct/kWhe and for new biomass plants up to 16.4 ct/kWhe, a bonus for biomass plants with the installed electrical capacity of < 500 kWe in the amount of 0,5 ct/kWhe within the auctions from 2021 till 2025, and the increment of the flexibility surcharge from 40 up to 50 resp. 65 EUR/kWe for new biomass plants.

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Within the amendment of EEG 2023, which is currently under review, the continuation of biomass auctions with flexibility requirements is envisaged.

To sum up, the most relevant regulations for the deployment of biogas resp. biomethane market in Germany are the EEG and RED with the GHG quota provision for fuels. The barriers for the development of biomethane are, however, a lack of planning security, complex regulations which are less harmonized with faster amendments in shorter time, lack of the overall political strategy, and ambiguity relating the priority of the pathways for biomethane use. Therefore, robust and long-term framework conditions as well as the planning security for the stakeholders are needed. The uncertainties resp. challenges embrace possible conversion of existing on-site electricity generation plants – especially larger plant facilities – to biomethane, which could provide significant contribution to the ambitious EU targets, focus on waste-based biomethane in line with the strong incentives driven by RED in the face of the question concerning the market for gas fuel vehicles with good options such as tractors or heavy-duty vehicles.

7.1.1 Data on feedstock usage and digestate production

In comparison with biogas production and on-site conversion, the production of biogas that is subsequently upgraded to biomethane is predominantly based on energy crops and, to a lesser extent, on energy crops in combination with animal excrements as substrate related to mass input.

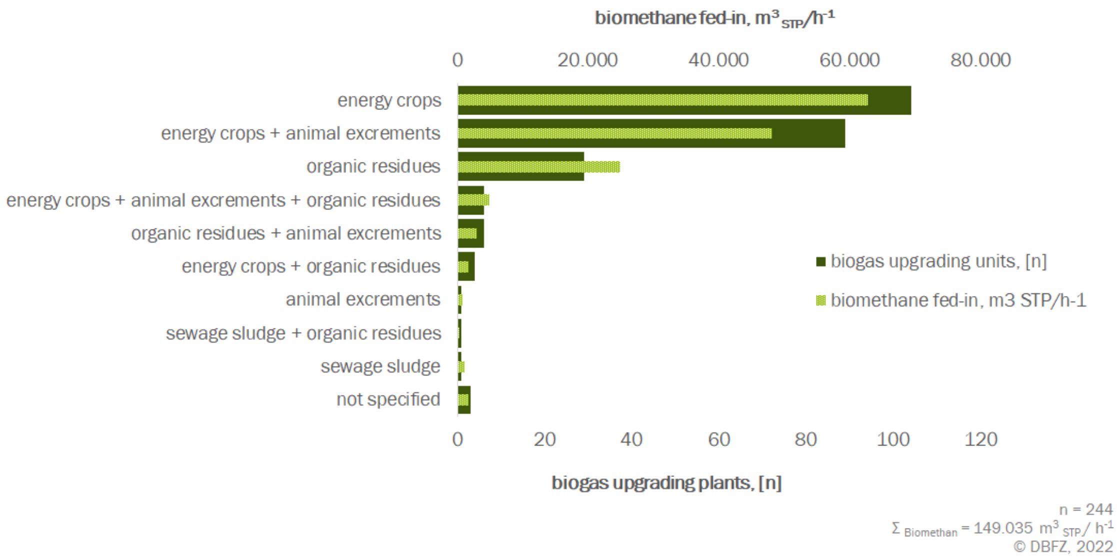

Figure 15 Substrates for biomethane production corresponding to the number of biogas upgrading units and respective amount of the fed-in biomethane in 2021 (DBFZ, 2022)

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The total amount of feedstock that was used in 2021 in order to produce biomethane is shown in the figure. In accordance with that, around 80 % of the feedstock used make up energy crops as well as the animal excrements, while municipal biowaste and organic residues account for 20 %.

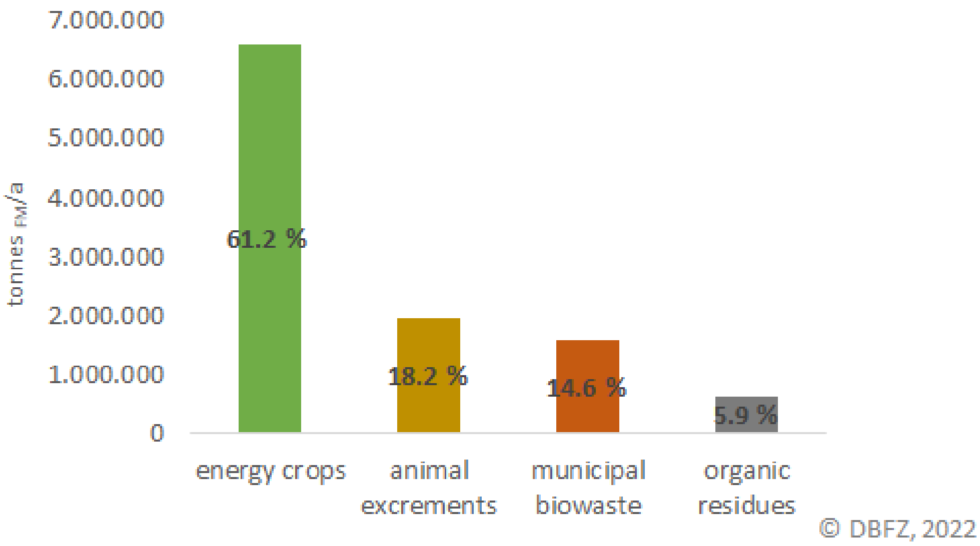

Figure 16 Feedstock for biomethane production 2021 (DBFZ, 2022)

Based on the substrate input the amount of digestate in 2021 can be estimated with approx. 115 mill. tonnes per year (cf. table, estimation for reference year 2021 based on plant operators' survey 2022):

Type of substrate	**Substrate input t fresh matter per year for biogas production**	**Substrate input t fresh matter per year for biomethane production**	**Substrate input t fresh matter per year in total (biogas + biomethane)**
Energy crops	58,050,191	6,610,264	64,660,455
Manure/ dung	63,358,136	1,968,152	65,326,289
Biowaste (municipal)	4,774,163	1,581,372	6,355,535
Other organic residues (Industry)	3,730,364	641,097	4,371,461
Total	**129,912,854**	**10,800,885**	**140,713,739**

Table 3 Substrate input for biogas and biomethane production in 2021 (DBFZ, 2022)

The (possible) utilization of specific substrates for biogas resp. biomethane production as well as the digestate treatment (return onto cultivated land) is partially linked to the European and

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German agricultural policy. At the European level, the Common Agricultural Policy (CAP) involves all EU member states supporting farmers. The proposal on the new CAP released by the European Commission in 2018 should provide support to the main goals of the European Green Deal. Whereas the new CAP is expected to enter into force in January 2023, a transitional regulation (Regulation (EU) 2020/2220) has to bridge the gap between the old and the new CAP in 2021 – 2022 with an extension of the previous regulations from the previous seven-year period 2014 – 2020. One of the CAP targets appears to be beneficial in particular with respect to the role of crop and feed residues within the future bioeconomy identifying the favourable use of "food and feed residues, farm waste or other bio-based resources to produce textiles, natural packaging (replacing plastic), construction materials (reducing the use of energy-intensive materials such as steel and cement) or to produce a clean and affordable energy (e.g. through biogas production)" (European Commission, 2020c). While pointing out the pivotal role of CAP, there are specific measures set with respect to the management of agricultural residues, in particular:

- Diminishing N-surpluses.
- Consulting and incentives for the reduction of CH4 emissions through improved timing of fertilization and management of crop residues (build-up of humus);
- Increasing anaerobic digestion based on manure and agricultural residues (Federal Government, 2019).

The raw material substrates for biomethane used in transport are mainly residual and waste materials. This substrate category represents between 60 and 93%. To a lesser extent, maize and small amounts of other food crops are also used. The GHG quota requirements, which favor substrates with high GHG savings, are the main driver for this distribution.

Type of Substrate	**2018**	**2019**	**2020**	**2021**
Waste/residual material	27,000 t	15,000 t	38,000 t	55,000 t
Maize/ Silage maize/whole crop	2,000 t	10,000 t	13,000 t	12,000 t
Cereal/whole crop			200 t	2,000 t
Beets			1,040 t	1,010 t
Grass/arable grass			40 t	300 t
Total	**29,000 t**	**25,000 t**	**52,280 t**	**70,310 t**

Further, the Biomass Ordinance as well as the Biomass Electricity Sustainability Ordinance are supplementary to the EEG prescribing requirements on types of (sustainable) biomass used eligible for electricity generation under the Renewable Energy Sources Act (Clearingstelle, 2016; Clearingstelle, 2022). By the Biomass Electricity Sustainability Ordinance as well as the Biofuel Sustanability Ordinance the Directive (EU) 2018/2001 is transposed into the national law.

In addition, there is a series of national German regulations (Fertilizer Act, Fertilizing Ordinance, Material Flow Balance Ordinance as well as Fertilizer Ordinance) which control the practice of fertilization based on nutrient balancing. Considering GHG emissions levels within the

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agricultural sector, focal for minimization of N- and P-surpluses as well as NH3 emissions from manure management is the Fertilizer Ordinance (DüV) with its most recent strictly reaching amending Regulation entered into force in May 2020 for all nationwide areas depending on site and soil type, specific conditions for periods for manure application, requirements for emission-reduced application techniques and application methods, upper limits for the application of nitrogen from organic fertilisers per hectareas as well as the regulation on storage capacities of organic fertilizers (Federal Council, 2020).

Historically, due to its high methane yield, maize was the predominant crop used for biogas and especially for biomethane production. In order to respond to the public food versus fuel and, more recently, food-feed-fuel debate, the utilization of maize silage and grain (including whole crop silage, corn-cob-mix, grain maize and ground ear maize) was limited to 60 % by so-called maize cap within the EEG 2012. Currently, the maize cap is set at 44 % and will be further reduced to 40 % in 2023, 35 % in 2024-2025 and 30 % in 2026-2028 under the planned EEG 2023. Consequently, there are efforts towards further utilization of alternative substrates such as wild plants and agricultural residues (straw, chaff, sugar beet leaves) for biogas resp. biomethane production. Despite their positive environmental effects and cost reduction potentials, the limitations are set by the efficient process chain and availability at the regional scale for agricultural residues and harmonization of national and European legal frameworks for wild plants. More specifically, there should be an allowance for using wild plants from ecological conservation areas according to the second pillar of the Common Agricultural Policy (so-called greening measures) for biogas production not only in Bavaria, Baden-Wuerttemberg, Lower Saxony, and North Rhine-Westphalia but in all German federal states.

7.1.2 Future feedstocks

While sales in the CHP sector are primarily generated from biomethane based on energy crops, biomethane as a transportation fuel is generated from waste and residues in the first place. Since biogas and biomethane are currently produced mainly from cultivated biomass, but the trend towards more use of residual materials is present, the question rises how to switch from energy crops to alternative substrates such as straw, catch crops, permanent crops, manure potentials, or the organic fraction of residual waste.

The biogas process can utilise any biomass that is not strongly lignified. It has no demand in terms of high contents of oil, protein, sugar, starch. The palatability of the substrate does not play a role, poisonous plants are not a fundamental problem. It is therefore also possible to use the growth of plants that would be unsuitable for feeding, together with a variety of residues and waste materials. With almost 10 % of Germany's arable land (incl. grassland) and more than 10 % of arable land currently cultivated with energy crops for biogas resp. biomethane production, this offers opportunities to enhance agricultural landscapes with productive crops.

Despite modern harvesting methods and technology, considerable amounts of agricultural residues currently remain on the field for which – with the exception of straw – there is basically no alternative use to anaerobic digestion. Substrates with an ecological added value are primarily straw, chaff, beet leaf, clover grass, catch crops and flowering plants. The first three in particular offer cost reduction potential under suitable conditions and with efficient process chains.

There are significant crop and environmental benefits associated with harvesting and using of these material streams. From a biogas perspective, the associated image benefits in particular

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are considerable. For example, chaff harvesting improves field hygiene and reduces the need for glyphosate. Beet leaf harvesting avoids nitrous oxide emissions, reduces the risk of nitrate leaching and improves the N balance. Intercrops improve soil fertility and nutrient balance, reduce nitrate leaching risk, contribute to humus supply, partially expand crop rotations and increase agrobiodiversity.

A central obstacle to the establishment of permanent crops as biogas substrates is the short duration of the changing framework conditions. The establishment of the stands causes high costs, which can be compensated in the course of ten years compared to maize silage due to the lack of costs for soil cultivation, seeds and plant protection. In combination with the necessary lead time for implementation (obtaining information on cultivation requirements, harvesting and processing technology, coordination with landlords to establish a permanent crop etc.), runtimes of at least 15-20 years are therefore necessary so that plant operators can use this option to increase agricultural landscape biodiversity. Another obstacle is the lack of recognition of biodiversity-promoting permanent crops for biogas production as agri-environmental measures in the sense of the greening obligation. This is only possible in the case of the cup plants (*Silphium perfoliatum*).

7.2 Italy

In Italy there were about 1,900 operating plants, with a total installed capacity of about 1,300 MWel, making Italy the second biogas market in Europe after Germany and the fourth in the world after Germany, China, and USA. In addition to the important number of biogas plants that prove the presence of a mature industry in the area, in Italy there are many other important drivers for the biomethane sector like a large number of natural gas vehicles and to a wide extension of the natural gas grids.

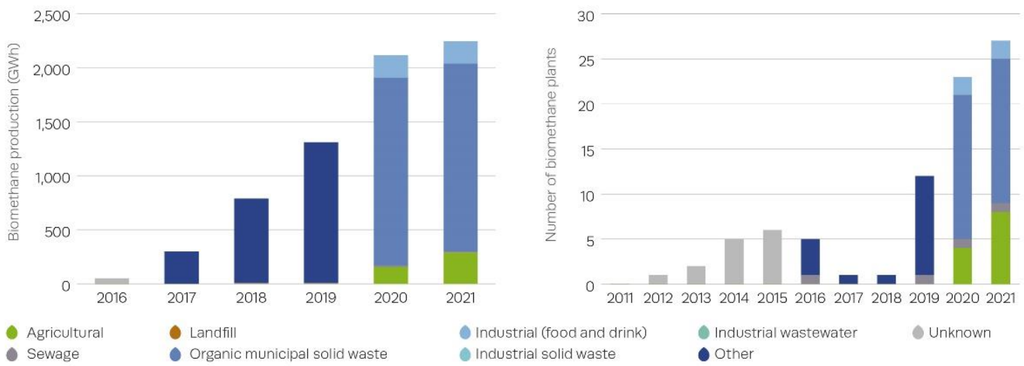

Figure 17 Development of biomethane production (GWh) (left); and development of the number of biomethane plants (right) Source: EBA Statistical report.

Indeed, there are more than 1 million of CNG and LNG vehicles, around 1,600 CNG and LNG filling stations and around 40,000 km of natural gas transmission grids and 250,000 km of distribution grids. Despite all these excellent premises, to date there are only 35 biomethane plants. To understand the reasons for this phenomenon it is necessary to carry out a detailed analysis of the evolution of biomethane regulations over the years and of the problems of each

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decree but since this is not the main objective of this deliverable, it will be analyzed later in the course of the project.

Support Schemes:

The 35 biomethane plants in Italy were built thanks to the support of the Italian biomethane Decree 02 March 2018. This Decree was originally planned to be in operation until 31 December 2022, but its duration has been postponed by 12 months, until 31 December 2023, according to Ministerial Decree of August 5th, 2022. It provides subsidies only if the biomethane is used in the transport sector as a biofuel, with a goal of 1,1 billion cubic meters of biomethane per year.

The biomethane promotion scheme is based on the allocation of certificates of release to consumption of biofuels ("Certificati di Immissione in Consumo di biocarburanti", better known as "CIC"). The system is based on the obligation that the subjects who release non-renewable fuels for consumption must produce renewable fuels or buy certificates (the CIC) to prove that they respect the % of renewable fuel production set by law every year. As a basic rule, one CIC is assigned every 10 Gcal of biomethane produced and released for consumption to the producers. The CIC is assigned every 5 Gcal if the biomethane derives from biogas produced by particular feedstocks (annex 3 to the ministerial decree of 10 October 2014).

Among the main innovations of the decree there was the introduction of specific measures dedicated to advanced biomethane. The biomethane is considered advanced if it derives from particular biomass (like organic fraction of municipal solid waste; agricultural by-products etc..).

A special favorable tariff is foreseen for the advanced biomethane: for the first ten years of operation, at the request of the producers of "advanced biomethane", the GSE (gestore servizi energetici) will withdraw the advanced biomethane produced at a “fixed value” and the GSE will also withdraw the certificate with a fixed value of € 375. Following this ten-year period, the producer will sell the CIC and the biomethane on the market.

The 35 biomethane plants have a capacity of around 350 Mm3/y which, as previously mentioned, are dedicated to the production of biofuels. Compared to the total production, about 80% of biomethane is injected into the natural gas transport or distribution grids and is sold, thanks to a mass balance mechanism, in compressed form in CNG fueling stations connected to the gas network. The remaining 20% of the plants sell biomethane after a liquefaction process.

In the existing plants, for the moment the Organic Fraction of Municipal Solid Waste (OFMSW), with 60% of the total, it is the most used feedstock to produce biomethane, followed by agricultural by-products, with 35% of the total, and sewage sludge, with 5% of the total.

The main reason for this prevalence of plants fed by OFMSW is not due to a greater availability of this biomass compared to the agricultural ones, but it is explained by the incentive mechanism introduced by the 2018 decree. In fact, the decree provided the same incentive tariff to produce biomethane from both OFMSW and agricultural waste and by products. Since the effective production cost of OFMSW, net of the other income of the treatment plant, is clearly lower than the production cost of the other matrices, the Italian biomethane market was characterized by a strong prevalence of plants that use OFMSW.

This and other barriers that influenced the 2018 biomethane decree were corrected by the new Italian Biomethane Decree, MD n. 340 September 15th 2022, published in the Official Gazette No. 251 of October 26th 2022. The new decree establishes incentives mechanisms, allocating

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1,73 billion EUR partially funds from the RRF, and combines assets and reforms for additional biomethane production (2.5 billion cubic meter per year by the end of June 2026).

The new decree has different tariff according to the type of feedstock. There will no longer be the same tariffs for biomethane produced by organic fraction of municipal solid waste and agricultural residues and by-products; indeed, the latter will receive a higher tariff. The biomethane produced can still be used to produce biofuels, including the maritime transport. In addition to the production of biofuels, biomethane can also be destined for other kinds of use.

The new decree has different tariff also according to the fact that biomethane will be produced by new plants or existent biogas plant converted to biomethane and according to the size of the plant. In addition to the incentive to produce biomethane, there is an incentive for the construction of the plants.

A significant growth in the sector is expected in the coming years thanks to the new decree and the changes made to the 2018 decree in the last year, which will remain active until the end of 2023. Indeed, Italy could achieve a production of 3.5 billion cubic metres of biomethane by 2027 and a production of 6.5 billion cubic metres of biomethane by 2030. The contribution of the organic fraction municipal solid waste (OFMSW) and other sectors (sewage plants, landfill) could be equal to 1.5 billion cubic meters of biomethane per year. The rest will be produced from agricultural biomethane.

To achieve the targets indicated above, the pillars for the development of the Italian agricultural biomethane potential are:

- **Limited use of first crops** (less than 200,000 ha, 3% of the Italian UAA in arable land in any case lower than the surface area once allocated to set aside)
- **Increasing the use of second crops**
- **Growing use of livestock manure in anaerobic digestion**
- **Growing use of agricultural residues and agro-industrial by-products**

The final use of biomethane will not be exclusively dedicated to the production of biofuels but will be destined also to other sectors, especially those that are difficult to electrify. It is expected that the production of biofuels from biomethane will represent about the 25% of all the biomethane production. To complete the description of the Italian biomethane scenario it is essential to describe the scenario of bioLNG sector.

The bioLNG sector produced from biomethane had a rapid and significant growth in the last four years thanks to the supporting framework that is made up by the same decrees of gaseous biomethane. In Italy there will be 10 bioLNG plants within 2022 making Italy the first country in Europe for numbers of plants. The growth of the sector will continue in next years; indeed, it is estimated that the number of bioLNG plants will be among 25 and 30 in 2023 with a production capacity of about one hundred thousand tons per year.

7.3 France

France began subsidising its biogas sector with the Renewable Energy Feed-in Tariffs (I) in 2001, revising the support system in 2002, 2006, 2011, 2016 and 2020. Additionally, biogas producers in France are eligible to receive support from the French Environment & Energy Management

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Agency (ADEME), as well as from local authorities, for studies and investment. The development of a favourable regulatory framework has underpinned the growth of the French biogas sector over the past two decades. Overall, the number of biogas plants in France rose from 287 to 945 between 2011 and 2021.

With a total of 365 biomethane plants by the end of2021 and already 465 plants inaugurated by August 2022. France is home to Europe's fastest growing biomethane sector. 151 biomethane plants began operation in France in 2021 (+71% compared to 2020) and another

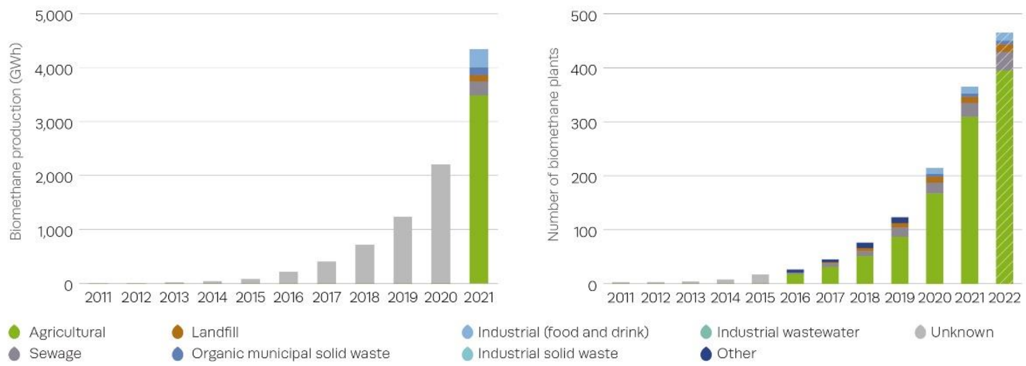

Figure 18 Development of Biogas Production (GWh) (Left) and development of biogas plants (right)

112 plants were installed between January and September 2022. France thereby largely surpassed Germany as Europe's biomethane leader in terms of the number of plants. The growth outlook for the French biomethane sector is secure for the comings years, thanks to 1,149 biomethane projects currently at various stages of development, representing a combined production capacity of 25.4 TWh/year. This production capacity could be operational before 2025, since a project takes 2 to 5 years to complete.

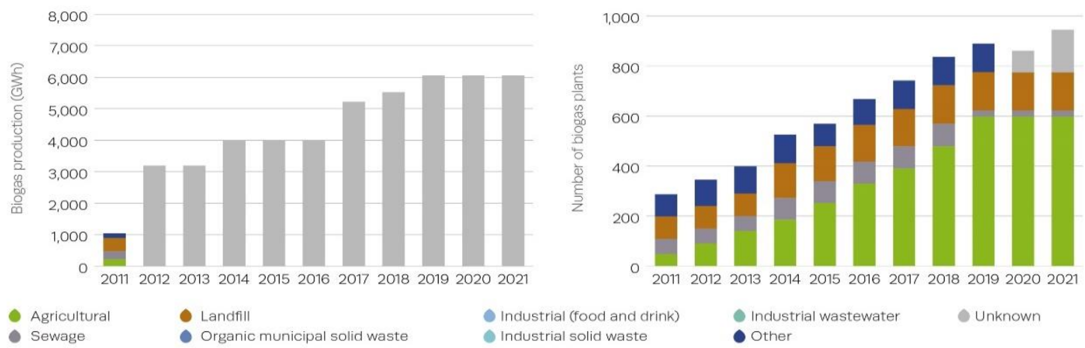

Figure 19 Development of Biomethane production in GWh (Left) and development of Biomethane plants (Right)

2021 saw the usage of 460 GWh (11%) of France's biomethane production in the transportation sector The nation is home to 153 filling stations that offer biomethane as a transportation fuel in a blend with natural gas; 128 of these stations exclusively offer compressed natural gas (CNG) or bio-CNG, 23 offer both CNG/Bio-CNG and LNG/Bio-LNG, and two stations solely offer LNG/Bio-LNG. Another 67 CNG/Bio-CNG stations and 17 LNG/Bio-LNG stations are being built. The CNG/Bio-CNG market in France is quite developed; all municipalities with more than 200,000 residents (except from one) have CNG/Bio-CNG buses or bin lorries, and one in four bin lorries and over 40% of buses sold in France utilize these fuels. 20% of CNG and LNG consumption in 2021 in France was covered by Bio-CNG and Bio-LNG.

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Support Schemes:

The biomethane sector benefits and will benefit in the foreseeable future from several support measures:

- Feed-in Tariff (since 2011)
- Operational support through tenders (since 2022)
- Biomethane production certificate (to be operational from 2025-2026)

Feed-In-Tariffs: Biomethane plants in France receive a Feed-in Tariff (FiT), which is guaranteed for 15 years. The FiT varies according to the size and the type of the plant, and a premium can be added for using specific feedstocks, such as manure (Figure 1). In line with the reduced ambition of the Pluriannual Energy Programme of April 2020, the Feed-In Tariff was revised downwards in November 2020.

A) For injected biomethane with a signed purchase contract before 23 November 2020

They benefit from the guaranteed tariff enacted by the Order of 23 November 2011. The producer receives a FiT between 46 and 139€/MWh, depending on the plant size and the feedstock types, for 15 years. The FiT is calculated based on a reference tariff and a premium depending on the inputs used. The reference tariff ranges between 45 to 95€/MWh for non-hazardous waste storage facilities (landfills) and between 64 and 95€/MWh for other facilities.

- The premium for municipal waste and household waste is 5€/MWh.
- The premium for waste from agriculture and agri-food varies between 20 and 30€/MWh, depending on the output produced.

The premium for wastewater treatment residue in sewage plants ranges from 1 to 39€/MWh.

B) For injected biomethane production plants:

- With a purchase contract signed after 23 November 2020
- With a forecast of annual prodcution less than or equal to 25GWh/yr (300 Nm3/h)

A revised Feed-In Tariff is applied based on Government's Decree and Order of 23 November 2020 and the Order of 13 December 2021. Both Orders provide the same rules and conditions for the FiT, except that the 2021 Order considers the inflation rate at the signature of the 15-year contract. Reference tariffs range between 55 and 99€/MWh for non-hazardous waste storage facilities (landfills), and 86 to 122€/MWh for other facilities. A premium can be applied for the use of livestock effluents and wastewater. Overall, compared to the provisions of the 2011 Order, these new terms create a reduction of 6-15% in the level of support. The FiT decreases by 0.5% each quarter. It can also go down more each quarter if the total number of contracts signed overshoots the target trajectory of the Government.

Operational support through tenders (since 2022)

All biomethane production facilities are eligible to the call for tenders organised by the State, but they are more suited for plants above 25GWh/year installed capacity. The ceiling price equals the floor price of the new FiT. The first tender is expected for 2023. Tenders in 2023 are expected support a total of 1,6 TWh of biomethane production.

Biomethane production certificate (to be operational from 2025-2026): Biogas Production Certificates (BPC) also known as Green Certificates in other countries, will create a third

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pathway of financial support. This scheme creates an obligation for gas suppliers to produce or buy non-State-supported biomethane to gradually integrate a share of biomethane in all their gas supply offers. This should lead to long-term contracts with biomethane producers. This scheme is expected to be operational in 2025-2026. It will be opened for plants of all sizes and types.

Guarantees of Origin

There is a well-functioning registry of Guarantees of Origin in France. GRDF is the government-mandated issuing body. It has been operating the registry since 2012 under a Public Service Delegation contract (PSD) with the French Government. The current PSD runs until end of 2023.

At the end of 2021, 53 suppliers and 12 non-supplier buyers were registered in the GO registry. The next PSD will include an opening to the biomethane European market, allowing traders, bidding for GOs. All Kinds of plants can issue GOs (except those supported through the biomethane production certificates), that can then be used by buyers and suppliers for the purpose of disclosing and proving the renewable origin of the gas consumed.

The “Right for injection” set a national approach for the grid operators to maximize the injection capacity for biomethane production.

Related to grid connection:

- It created an obligation for the grid operator to address connection requests of a producer even if they are located outside of a gas-served area.

- Network operators can pay up to 60% of costs of the grid connection.

- A cost-sharing mechanism is applied for grid connections and pressure stations that are expected to be used by new plants commissioned later (this avoids the practice of “first arrived, first paying”).

Related to grid reinforcement: A systematic mapping of future grid reinforcements is setup based on biomethane potential (instead of a case-by-case approach each time a project emerges). Grid operators must work together to deliver a “grid connection and reinforcement plan” per small area. The National Regulatory Authority assesses and validates the plan and investment proposals, using technical and economic criteria. Biomethane producers may have to pay a fee per MWh of biomethane injected depending on the need for shared compressor or grid reinforcement at their location (between €0.4-0.7/MWh). By December 2021, the National Regulatory Authority had validated “grid connection and reinforcement plans” that are expected to lead to 33 TWh of biomethane.

Non-injected biomethane:

A call for proposals will be launched mid-2023 for a volume of 1 TWh of non-injected biomethane. Selected applicants will benefit from a complementary revenue to the revenues from direct distribution as a fuel (at least 50 % of the biomethane produced by the plant shall be used as a fuel). The contractual specifications are still being prepared at the time of publication of this Summary. The sustainability conditions for biomethane are derived from the Article 29 of the RED II and are applied as follows:

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• Historically, France decided to cap the share of dedicated crops at a 3-year average of 15% of the total feedstocks for each production plant. Compliance with this limit will be integrated in the certification process, as the mass balance certification will allow it.

• For all injected biomethane, the French State decided to transpose the RED II‘s GHG emission reduction threshold applied to heat for all production plants: the threshold is 70% of GHG emission reduction for plants commissioned after 1 January 2021 and 80% for plants commissioned from 1 January 2026. This does not apply for non-injected biomethane (bio-CNG and bioLNG distributed on-site or by road transport).

All biomethane plants having a capacity larger than 19,5 GWh/year must be certified. Producers will have to refund the state aid it received (for instance the corresponding amount of FiT) for each non-certified batch of biomethane produced. There is no national certification scheme to date in France. French biomethane producers must use voluntary schemes recognized by the European Commission.

7.4 United Kingdom

The United Kingdom is the second the largest producers of biogas and biomethane in Europe. Over the last decade biomethane production has risen considerably, rising from 5 units in 2011 to 106 in 2020, producing a total of almost 7 TWh of biomethane. With its 117 biomethane plants which in 2021 produced a 6.2 TWh of biomethane, the UK has the third highest number of biomethane plants in Europe, surpassed only by Germany and France.

According to official Government statistics, heat produced by biogas combustion, totaled 1,254 GWh in 2020. This is 8% of the total heat produced under the non-domestic Renewable Heat Incentives (RHI) for 2020 and an increase of 29% from 2019 (973 GWh). The heat produced by biomethane is estimated to be 3,960 GWh in 2020. Power generation through anaerobic digestion (AD) has continued to see steady growth with a rise of 7% between 2019 and 2020. Growth rates have been relatively consistent for the last three years, with annual generation reaching 3,1000 GWh in 2020.

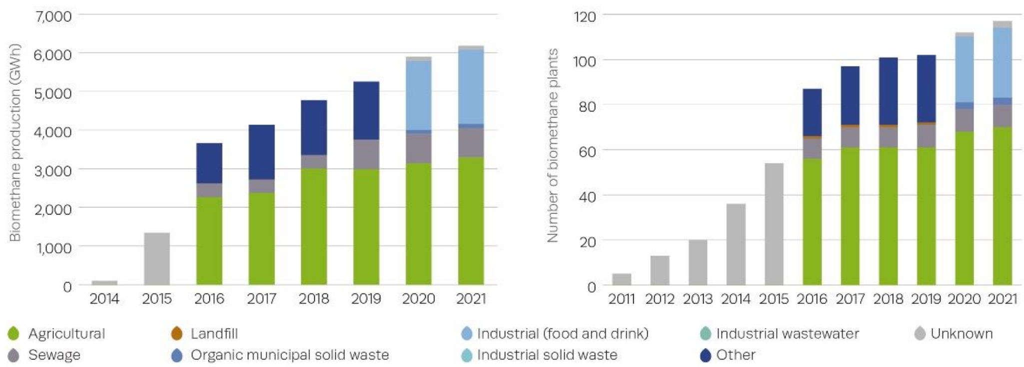

Figure 20 Development of biomethane production (GWh) (left); and development of the number of biomethane plants (right) Source: EBA Statistical report.

Support Schemes

Renewable Heat Incentive:

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The success for the biomethane market in UK is through some influential factors and support schemes which has been implemented under the Renewable Heat Incentives (RHI). The RHI provides a Feed-in-Tariff (FiT) for biomethane produced under anaerobic digestion and injected into the natural gas network. Biomethane installations are paid per amount of energy injected; the rate they receive varies according to plant size and year of commissioning. The subsidy lasts for 20 years. The scheme was implemented in 2011, explaining the increase in biomethane plant numbers from that year onwards. The RHI only applies to Great Britain (England, Wales and Scotland). Northern Ireland has a separate subsidy system for renewable energy that does not include a feed-in-tariff for biomethane. For biomethane to be eligible for this subsidy the installation must show that certain sustainability criteria have been met including:

- That the lifecycle emissions of the production process including any emissions from energy crop cultivation are no more than 34.8 gCOe/MJ (LCV)
- That any energy crops do not impact on land which acts as a carbon sink.

In addition, the scheme includes feedstock restrictions, requiring at least 50% of the biomethane output to be derived from wastes and residues before RHI payments are reduced. Biomethane use in transportation is supported by a Quota system called the Renewable Transport Fuel Obligation (RTFO). Obligated suppliers must show that a certain percentage of fuel they supply is renewable and they may do this by suppling renewable fuel themselves or buying Certificates generated from others that have. Aside from the FiT level other important factors are:

- **Feedstock supply**: developers have been successful in negotiating supplies of energy crops; however, the government has moved to reduce incentives for these projects. Sourcing reliable and secure waste and residue streams e.g., domestic, and commercial food waste collections is a challenge and projects have had to adjust their expectations of income generation via gate fees.
- **Grid capacity**: new plants must find sites where there is enough capacity to inject their gas, which is a particular problem on parts of the grid which have very low demand in the summer. A new support mechanism has been introduced in the UK by autumn 2021 to support further biomethane injection.

Green Gas Support Scheme:

The Green Gas Support Scheme is a levy funded scheme designed to support the deployment of new biomethane injection into the gas grid produced via anaerobic digestion. The GGS launched on 30th November 2021 is scheduled to run up until 2025.

Similarly, to the RHI, at least 50% of the biogas in the Green Gas Support Scheme must be derived from wastes or residues to encourage more processing of wastes and residues rather than energy crops. In addition, to minimize ammonia emissions from digestate, all digestate from plants supported under the scheme must be applied with low emission spreading equipment as per COGAP for Reducing Ammonia Emissions. If spread by a contractor, digestate must follow the relevant industry standards (NAAC). The table below shows a comparison between the tariffs provided under the GGSS and those provided under the RHI.

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Technology	Annual Injection (Vol)	Tariff (p/KWh)	RHI Rates (p/KWh) since 2019.
Biomethane Injection	Tier 1: First 60,000Mwh	5.51	4.92 (first 40,000)
	Tier 2: Next 40,000 MWh	3.52	2.90
	Tier 3: Remaining MWh	1.56	2.24

Table 4 Comparison between the tariffs provided under the GGSS and RHI

Renewable Transport Fuel Obligation:

The Renewable Transport Fuel Obligation (RTFO) is the Government policy for reducing GHG emissions from fuels supplied to transport. The scheme functions as a traded obligation on fuel suppliers to supply an increasing volume of renewable fuels - set to 2032. Obligated suppliers can either redeem sufficient Renewable Transport Fuel Certificates (RTFCs) or buy out at **50p/litre**. RTFCs are awarded to each litre of renewable fuel (or Kg for gaseous fuels) supplied at the duty point. Biomethane is eligible under the RTFO and is awarded 1.9 RTFCs per Kg and double the number of certificates (3.8) if made from wastes. Any biomethane used within the RTFO is reported by the UK government against its targets for renewable fuel. The United Kingdom produced a total of 138 GWh of Bio-CNG and 37 GWh of Bio-LNG in 2020, meaning that the share of UK's biomethane production which is used in transport is 2.5%. The UK is home to 21 Bio-CNG and 12 Bio-LNG filling stations.

Feedstock for Biomethane

Agricultural waste is the most important feedstock for the UK's biomethane production; 82% of all biomethane produced in the UK in 2021 originated from agriculture-based biomethane plants, which correspond to 70 facilities. Next, 31 biomethane plants used industrial wastes from food and drink industry, 10 plants correspond to sewage sludge facilities and 3 further plants were organic municipal waste based.

A total of 11,080 ktonnes wet weight of substrates were used for biogas production in 2021 according to the UK's statistics. 2,849 ktonnes were made up of agricultural residues such as manure and crop waste. Another 2,598 ktonnes of substrates were made up of sequential crops and dedicated crops. Organic municipal solid waste made up 3,795 ktonnes. The remaining 1,837 ktonnes were classified as other feedstocks.

Digestate in the UK is generally classified in two categories: **digestate having a waste status and digestate having a product status**

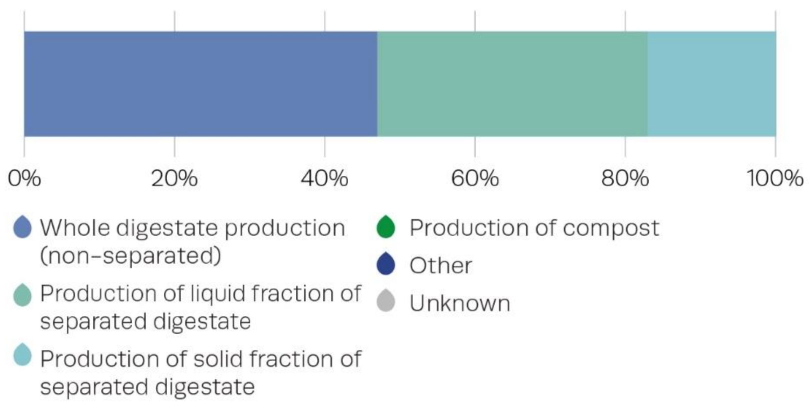

Figure 21 Source of Digestates in the UK

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7.5 Denmark

Denmark started biogas production in the mid-seventies; biomethane production on the other hand began in 2015 and grew substantially over the years, rising from 1 plant in 2012 to 51 plants in 2021. By 2018, biomethane production in Denmark had overtaken Danish biogas production. Denmark, Sweden, and Estonia are to date the only European countries to report more biomethane than biogas production. With an increase of 1,642 GWh in Danish biomethane production in 2021 reaching a total biomethane production of 5,683 GWh, Denmark is one of the fastest growing biomethane producers in Europe.

The rapid growth of the Danish biomethane sector reflects the country's ambitious renewable gas targets. The Danish parliament enacted a new energy agreement in June 2018 stating that the country, in line with the Paris agreement, will work to reach net zero emissions by 2050 and achieve 55% renewable energy by 2030. The agreement includes a phasing-out of the current biogas and biomethane subsidy frameworks and the introduction of a new scheme for biomethane injected into the gas grid based on tenders. This amongst other support schemes have become an enabling force for the biomethane market in Denmark.

Denmark is the third biggest biomethane producer in Europe, following behind Germany and the UK. A survey performed by the Danish biogas association in spring 2022 indicated that 30 biomethane plants are considering increasing production and 40 new biomethane projects are under development.

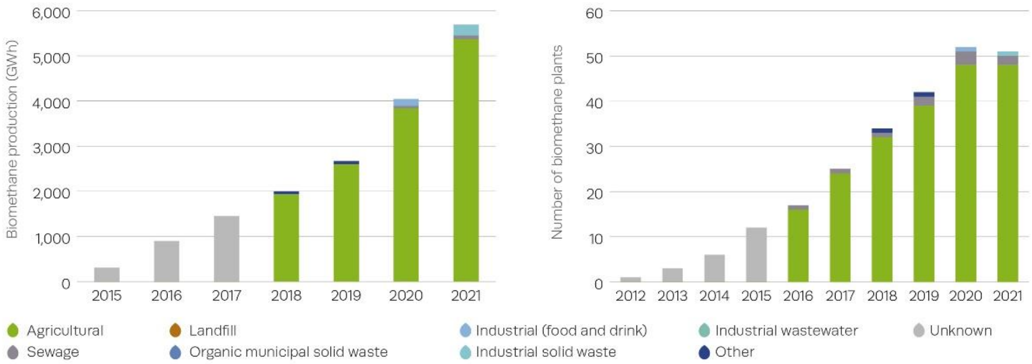

Figure 22 Development of biomethane production (GWh) (left); and development of the number of biomethane plants (right) Source: EBA Statistical report.

Support Scheme:

In 2014 the EU ratified the national legislation regarding the energy enactment. The new agreement included a feed-In-Tariff for biomethane injection int the gas grid.[48] This also included feed-in-premiums which are adjusted annually: A **base subsidy** provided a fixed amount to the producer received. This was regulated with the consumer price index (usually 60% of the change of the price). Biomethane injection was pegged at 0.039€/KWh in 2018.

Temporary subsidy: was applicable to initiate biogas projects. At the price of 0.005€/KWh. Finally, a Gas price subsidy. The energy agreement approved by the Danish government has provided a budget of 32 million euros over a period of 20 years. This is to help promote primarily renewable energy gases production in the country. This will be assigned based on tender pricing.

[48] David Johnson.

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Guarantees of origin: Denmark established a national registry which has been in place since 2011. As a guarantee of origin, Eneginet Denmark issues certificate to the biomethane plants which can be sold and allows the gas supplier to document that renewable gas has been injected into the grid. This certification fulfils the REDII as guarantees of origin.

In 2020 The Danish Parliament agreed on a new support scheme based on tenders to increase competition. The tenders apply for biomethane production, either by upgrading of biogas or e-methane produced by CO2 from the upgrading plant and renewable hydrogen. New biomethane production can bid on the tenders, which will provide support in the form of a feed-in premium for a 20-year period.

The bids must reflect the support required per GJ as well as the amount of biomethane they are bidding for. The intention is to have 6 bidding processes in the coming years. The winner(s) of the bidding process will be the lowest bid(s) until the budget for that round is empty.

To avoid unnecessary support, an aid limit has been implemented by a gas price of 120 kr./GJ (approximately 16,1 euros/GJ). If the gas price exceeds this limit, the support is reduced proportionally. The budget for the new scheme is set 1.7 billion euros and is estimated to reduce GHG emissions by 0.2 million tonnes CO2e in 2025 and 0.7 million tonnes in 2030.

The first bidding round has a budget of 27 mil. Euros and is expected to be held in 2023 with aid payments starting in 2024.

Mil. Euro	2024	2025	2026	2027	2028	2029	2030
Tenders	27	16	0	10	10	12	12
accumulated	27	43	43	53	63	75	87

The biomethane produced with the tenders are subject to sustainability requirements from the REDII. Likewise, the hydrogen used in the process must comply with EU-regulation on the area. Furthermore, biomethane must comply with the national requirements on use of energy crops, as well using biomethane instead of natural gas in operational processes if these processes are operated on gas. The scheme is currently under state aid approval by the EU Commission

7.6 Switzerland

Switzerland has been producing biomethane since the end of the 1990s, they also pioneered the injection of biomethane into the gas grid. This has been characterized with the continued increase in the past decade in the production of biomethane in the country. However, the Swiss government is yet to implement a specific support scheme for biomethane production.

Currently, the federal subsidy scheme is applicable to electricity from biogas only and biomethane injected into the gas grid is not eligible. However, the Swiss gas distributors, organized in the Swiss Gas Industry Association (VSG), have set up a fund to support new or expanded biomethane plants. Additionally, biomethane use in transport is exempt from several fossil fuel-related taxes. Although current legislation does not set specific targets for the development of biomethane, the VSG includes as a target the achievement of a 30% share of biomethane in gas consumed in the heating market (excluding industry) by 2030. The trading

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and use of biomethane is tracked via the VSG's "Clearingstelle", operated under a mandate from the customs authority.

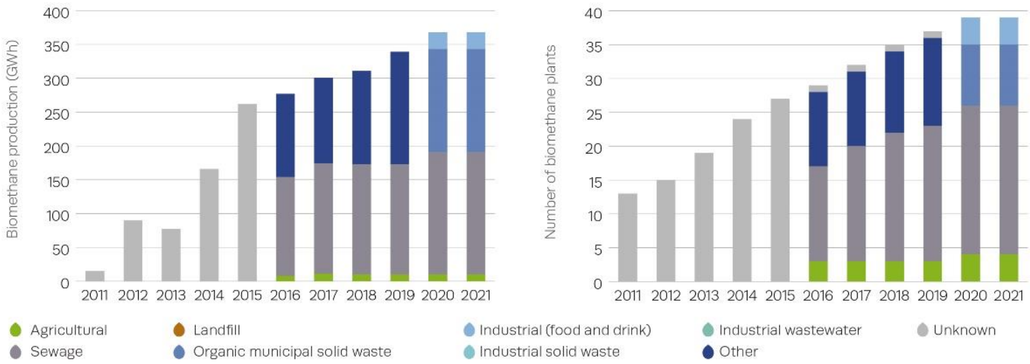

Figure 23 Development of biomethane production (GWh) (left); and development of the number of biomethane plants (right) Source: EBA Statistical report.

In 2021, biomethane covered 27% of the gases used as vehicle fuel. However, the government considers only up to 20% to be exempted of mineral oil tax. There are currently 153 Bio-CNG filling stations across Switzerland, serving approximately 13,500 gas vehicles. All newer filling stations provide the option to choose between 20% and 100% biomethane.[49] For producing its biogas, Switzerland uses approximately 4 million tons wet weight of sewage sludge, 1 million tons wet weight of agricultural residues such as manure and 734,000 tons wet weight of organic municipal solid waste In addition, 250,000 tons COD of industrial waste is being used for biogas production. The industrial wastes are expressed in tons COD instead of tons wet weight because part of the feedstocks which stem from the food and beverage industry are highly diluted. Share of different types of feedstocks usage for biogas and biomethane production in Switzerland in 2021

7.7 Austria

Austria covers more than a fifth of its energy needs from gas. There are currently around 300 biogas plants in Austria. In order for this biogas to be fed into the gas network as biomethane, the CO2 it contains, and other accompanying substances must be separated in the processing plants. At the end of 2021, Austria counted 16 biomethane plants. While one sewage-based plant was inactivated in 2020, an existing biogas plant was expanded with a biogas upgrading unit and biomethane grid injecting in 2021, bringing the number back up to 16. There is only a track record of the injected biomethane into the gas grid in Austria. This means total biomethane production, including off-grid production, is not documented. The data shown thus represent the biomethane injected into the Austrian grid. The production from non- connected plants and off-grid self-consumption are not considered. The highest biomethane injection of approximately 170 GWh was achieved in 2018. In 2021, 135 GWh of biomethane was injected.

5 biomethane plants have a Bio-CNG fuelling station directly at the production site; two of them are for internal use only and not accessible for the public. One additional plant has a direct

[49] EBA Statistical Report 2022

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biomethane pipeline to a public fuelling station. In total, there are 4 public Bio-CNG fuelling stations in the country. No Bio-LNG production takes place in Austria.

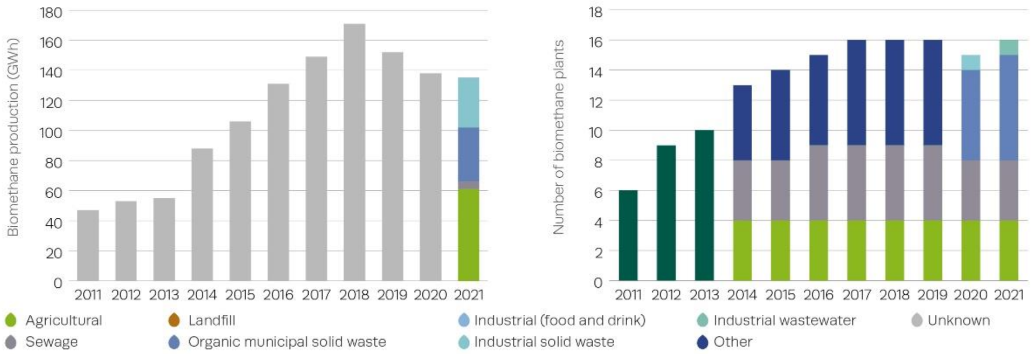

Figure 24 Development of biomethane production (GWh) (left); and development of the number of biomethane plants (right) Source: EBA Statistical report.

In total, around 15 million m3 of biomethane is produced there. Still, most of the biogas is converted into electricity and heat on site. (Kompost und Biogasverband Österreich) However, the degree of efficiency is significantly lower than in the processing of biomethane, where more than 90 percent can be achieved.

Support Schemes:

Renewable Electricity Act (Ökostromgesetz, ÖSG)

The promotion of the conversion of biomethane into electricity was introduced with the second amendment to the Renewable Electricity Act in 2008. Specific tariffs were set for the first time in the Renewable Electricity Regulation 2011. Renewable power generation from biomethane, produced and injected at a different location than its conversion to renewable power after grid withdrawal, were from that point on also supported via specific feed-in tariffs.

The injected and transported biomethane and the change in ownership from the biomethane plant operator to an electrification plant (CHP) operator providing renewable electricity from biomethane must be tracked via biomethane certificates. The Austrian balancing group coordinator, currently AGCS Gas Clearing and Settlement AG, is mandated for the monthly issuing of such biomethane certificates. The subsidy is paid to the electrification plant (CHP-unit) operator who must organise the ownership transfer of certificates with the registered biomethane plant operators. Hence, these subsidies are considered indirect support for biomethane, as the biomethane itself does not receive a subsidy.

To obtain the subsidies within the Renewable Electricity Act, the process of having biomethane certificates audited by independent experts (auditor) is mandatory. In practice, these audits comprise plausibility checks balancing the input materials and the produced and injected energy amounts as well as an assessment of the used input/substrate criteria. The audit report must be made available to the electrification plant (CHP) operator and lastly to the Renewable Power Settlement Agent (OeMAG). Hence, the Biomethane Registry Austria provides a system for auditors to attach audit reports to specific biomethane certificates and add relevant audited information to the respective certificates.

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The support tariffs are determined in the respective Renewable Electricity Feed-in Tariff Regulation. The following graph shows an overview of FiTs (green for electricity from biogas and orange for electricity from decentralised biomethane transported via the gas grid).

Renewables Expansion Act (Erneuerbaren Ausbau Gesetz, EAG 2021)

The Renewables Expansion Act forces a shift from biogas (renewable power generation) to biomethane (renewable gas generation). Although there are no direct production subsidies for renewable gases made available, there are some specific incentives for renewable gas(es):

- There are investment subsidies for the conversion from biogas to biomethane installation and for new biomethane installations.
- A Green-Gas Service Agency will be procured by the Ministry of Climate Protection to support the uptake of the Austrian renewable gas market.
- The government envisions a green-gas-quota for gas suppliers. The implementation will require an additional Green Gas Law which is not yet in place.

The implementation of investment subsidies will be separated over two different implementation regulations. The Implementation Regulation Power regulates investment subsidies for renewable power plants and came into force on 06/04/2022. The implementation of regulation for renewable gas plants is outstanding.

Investment subsidies are merely granted as contributions to impending investment costs and will be eligible for:

- newly built biomethane plants, and
    - max. 30% contribution,
    - max. funding contingent of € 15 Million/year,
- for the conversion of biogas to biomethane installations
    - max. 45% contribution,
    - max. funding contingent of € 25 Million/year.
- for investment costs on gas grid connection.

Investment subsidies may also be granted for plants for conversion of electricity into hydrogen or synthetic gas. A max. funding contingent of € 40 Million/ year will be provided for plants with an installed electrical capacity of 1 MW, with prerequisites that the

- plant produces only renewable gases,
- plant obtains only renewable electricity.

The Green-Gas Service Agency has been granted a license by the Ministry of Climate Protection which started beginning of 2023. Its task will be the provision of advisory services to market participants of the Austrian green gas market as well as keeping market overview and submitting an annual report to the Ministry of Climate Protection. An electronic platform that promotes the exchange of supply and demand for different kinds of services between producers or generators of renewable gases and suppliers shall be implemented and maintained.

Austrian Gas Guarantees of Origin

The Austrian system for gas Guarantees of Origin is enshrined in §§81-84 Renewable Expansion Act, § 129b, § 129c, § 130 Gas Economy Act and Regulation on Gas Labelling. These pieces of legislation represent the national implementation of Art 19 RED II.

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Gas Economy Act (Gaswirtschaftsgesetz, GWG 2011)

One of the laws which underwent amendment because of the Renewable Expansion Act is the Gas Economy Act. Amendments on § 129b, § 129c, § 130 – specific to renewable gases – concern the rules on end consumer disclosure (also often referred to as "Gas Labelling" in Austria). On the annual bill for their end consumers, gas suppliers are requested to inform about the origin of gases providing percentages of gas composition concerning the gas types such as biogas, landfill gas, sewer gas and fossil gas. The technology applied to generate the respective energy carrier must be proven by a recognised auditor.

Regulation on Gas Labelling (Gaskennzeichnungsverordnung, Gken-V 2019)

A partial implementation of the Renewable Energy Directive (recast) was already reached with the implementation of the Regulation on Gas Labelling which was later accompanied with the amendments of the Gas Economy Act. The amended regulation was published on 11/04/2022. The regulation provides requirements for labelling (consumer disclosure) of the origin of gases which must be proven by Guarantees of Origin, according to Art 19 RED II. As issuing body for Guarantees or Origin and as the monitoring authority for consumer disclosure, the Austrian energy regulator E-Control was mandated

7.8 The Netherlands

The Netherlands is one of the pioneering countries in biomethane production. In effect they have had several positive impacts on their biogas and biomethane markets. Support from Feed in Premiums (FiPs) is by large a great contributor to this increase. The biomethane market grew rapidly between 2016 and 2021, rising from 21 active plants to 71. More than half of these plants run on agricultural substrates such as manure or from industrial wastes.

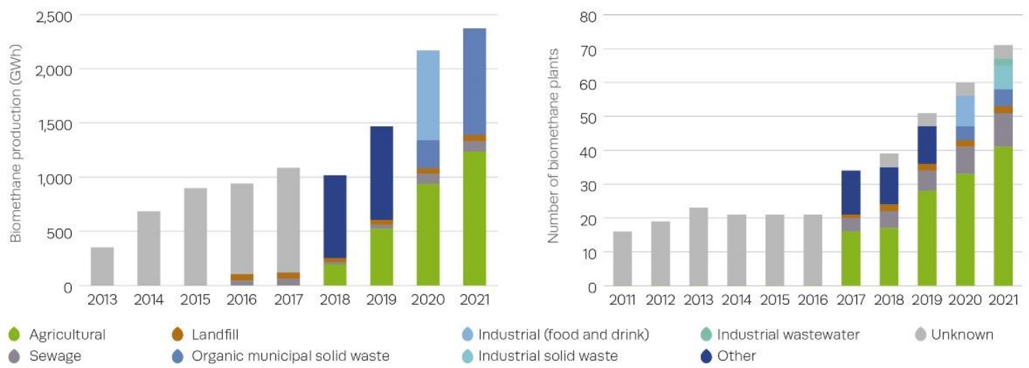

Figure 25 Development of biomethane production (GWh) (left); and development of the number of biomethane plants (right) Source: EBA Statistical report.

Of the 71 biomethane plants in the Netherlands, 66 of them are known to be connected to the gas grid. 54 of the 71 Dutch biomethane plants use membrane technology to upgrade their raw biogas. Chemical scrubbing is used in 9 plants and 6 plants use water scrubbing as their upgrading technology.

As far as feedstocks are concerned, energy crops are not used in The Netherlands for biomethane production. In addition, the Dutch national renewable gas registry has been

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operated by Vertogas, a subsidiary of the Nederlandse Gasunie, since 2009. The registry has a mandate from the Ministry of Economic Affairs and Climate (EZK) since January 2015, obligating renewable gas producers to register and certify via the Vertogas in the Netherlands.

About 20% of the biomethane produced in the Netherlands are used in transport in 2021. The country is making significant investment in Bio-LNG production, there is an anticipated addition of 10 Bio-LNG plants in the period of 2022 – 2025. This will increase the total production to about 2 TWh per year by the end of the same period. The Netherlands produces Bio-CNG as well as Bio-LNG. Four biomethane plants produce Bio-CNG onsite and there are over 170 public filling stations in the Netherlands offering Bio-CNG.

Support schemes such as the simulation of sustainable energy (Stimulering Duurzame Energie producie, SDE+) support the development of renewable energy in the Netherlands in 6 categories: biomass, geothermal energy, water, wind (on land, lakes and wind on water defence walls) and sun It serves as an operating grant which provides financial compensation to producers of renewable energy (i.e renewable gas, electricity and CHP).[50] For the production of biomethane and the injection into the gas grid, a subsidy with a duration of 12 years can be awarded. SDE+ compensates for the price difference between the market and the production cost price, comparing them to fossil fuel prices. Hence the producer receives a contribution based on the current market price trend.

The tender amount for renewable gas applications is divided by a factor of 0.706 when ranking, as renewable gas counts for 70.6% of the renewable energy target for 2020. Each tender, a maximum tender amount is fixed. The SDE+ spring 2020 tender has 3 phases, each with a maximum tender amount. First phase 1 will open with a max amount of € 49 / MWh, next phase 2 (max 56 € / MWh) and phase 3 (max 92 € / MWh).

The SDE + spring 2020 is the last opening round in its current form. After the spring round, the scheme will be expanded under the name Sustainable Energy Transition Incentive Scheme (SDE ++). The SDE ++ scheme will stimulate the roll-out of renewable energy and CO2-reducing technologies by compensating the unprofitable top of these technologies.

Nearly all biomethane supplied to transport is sustainable in accordance with the sustainability requirements of the EU renewable energy directive and Dutch regulations. This is demonstrated by ‘green gas’ certificates. Each certificate represents produced biomethane elsewhere in the Netherlands. At the gas station, which is connected to the gas network, the upgraded biomethane becomes compressed (bio-CNG) and pumped into the tank of a vehicle under high pressure. The gas must be of at a minimum of 82% methane. The number of public service stations where compressed natural gas and upgraded biomethane are offered in The Netherlands is over 170 and still growing. At more than half of all CNG filling stations also 100% upgraded biomethane is available.

7.9 Sweden

Ranking third in the total number of upgrading units within Europe after Germany and UK, Sweden has some of the most ambitious overall national GHG emission targets for 2030 and 2045 that are set in the Swedish climate law. A production goal of 10 TWh of biomethane by 2030 is proposed in the Swedish Biogas Market Investigation which is yet to be approved by

[50] David Johnson

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parliament. Sweden, Denmark, and Estonia are to date the only European countries to report more biomethane than biogas production.

Sweden began offering indirect backing for biogas as early as 1991, with its taxation framework for Energy, Carbon Dioxide and Sulphur. The energy and carbon tax exemption for biogas use in transport and heating (including industrial process heat) has been the main driver for biogas and biomethane development ever since, along with investment support schemes for plants, filling stations and vehicles.

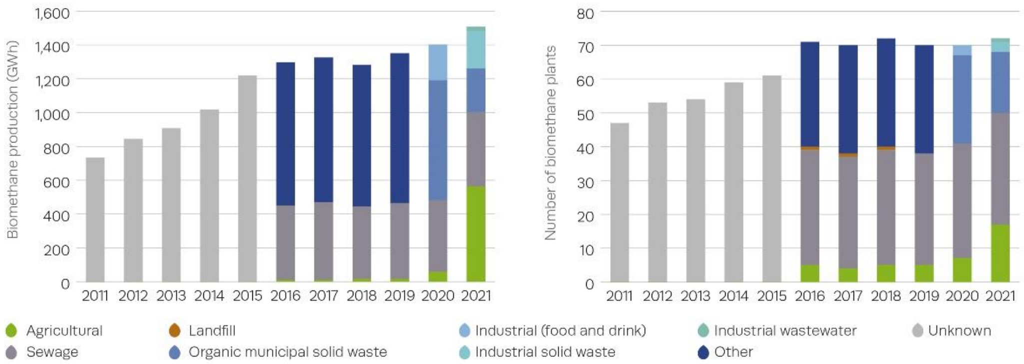

Figure 26 Development of biomethane production (GWh) (left); and development of the number of biomethane plants (right) Source: EBA Statistical report.

The number of biomethane plants in Sweden grew from 47 in 2011 to 72 in 2021. Majority of these plants are off grid; made up of local and regional grids, and stand-alone plants with on-site filling stations. Within the same period biomethane production also increased from734 of 1508 GWh.

The gas infrastructure in the country is limited to the south-western part where the transport grid is connected to the European gas network via Denmark. The share
of biomethane in the south-western grid was 34% in 2021. Also, the regional network in Stockholm, is fueled with locally injected biogas and LNG that is shipped in from further afield; the share of biomethane in the Stockholm grid was 78% in 2021. There are also several other local biomethane grids. Aside the existing gas infrastructure, a significant part of biomethane produced in Sweden is transported by road as bio-CNG and, to a limited but increasing extent bio-LNG.

Out of 72 Swedish biomethane plants, 16 plants are connected to the grid in Stockholm or southwestern. Sweden whereas 55 plants do not have a grid connection or use a small local grid 68 plants produce Bio-CNG on site, while three plants produce Bio-LNG on site.

End Use: Due the tax exemptions available for biomethane production most of Sweden's biomethane is used in the transport sector, which in contrast has high taxes. If not the produced biomethane is used for heating. Out of 1,508 GWh of biomethane produced in Sweden.
in 2021, 1,101 GWh (73%) was used for road transport. The market for (Bio-)CNG and (Bio-)LNG is well developed in Sweden but is highly dependent on the policy incentives and long-term support systems in place. There were 272 Bio-CNG filling stations and 26.
Bio-LNG filling stations in Sweden by the end of 2021.

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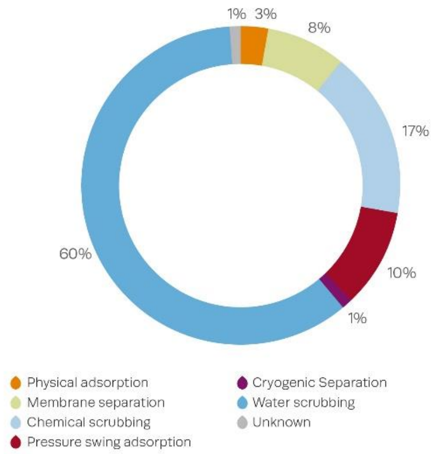

Figure 27 Biomethane Upgrading technologies in Sweden

Other support Schemes:
Biomethane production support: A subsidy that was set up for a year in 2018 to assist local biomethane producers against competition from imported biomethane. This policy has a budget setup of 36M euros (with a support of 0.03€/KWh).

Klimatklivet: An investment package setup in 2015, aimed at support up to 45% for all measures that reduced GHG emissions. In 2018 a budget of 1.5 billion SEK/yr (0.14 billion euros) was set up. A proposed increase in the budget to 2.3 billion SEK/yr (0.21 billion euros. This investment policy is active until 2023.

7.10 Norway

The Norwegian biogas and biomethane sector can be divided into three parts: facilities that convert their biogas to biomethane, which is then liquefied (producing bio-LNG); facilities that do not convert the biogas but instead compress it as biogas; and smaller facilities that produce biogas primarily for on-site use. Three sizable plants that were all operational by the end of 2021 make up the group of facilities that produce bio-LNG. In 2022, two more plants began construction.

This group of plants accounts for most of the biogas production in Norway. The second group are smaller plants compressing their non-upgraded biogas on-site. This Bio-CNG can be used directly in buses or trucks. It is estimated that around 14 of these plants were in operation by the end of 2021. The third group are smaller biogas plants which do not have a relevant impact on the biogas and biomethane markets in Norway and are therefore not considered in the Norwegian statistics. Norway produced more than 700 GWh of combined biogas and biomethane in 2021, while the exact amount has not yet been made public. Norge Biogas states that at least 12 further Norwegian biomethane projects are in the planning stages; these projects are anticipated to significantly boost global biomethane production in 2022 and 2023.

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The majority of Norway's biogas and biomethane production comes from sewage sludge (50%) and industrial solid waste, primarily food waste (33%), with smaller amounts coming from manure (2%), various types of feedstocks (15%), and other sources.[51]

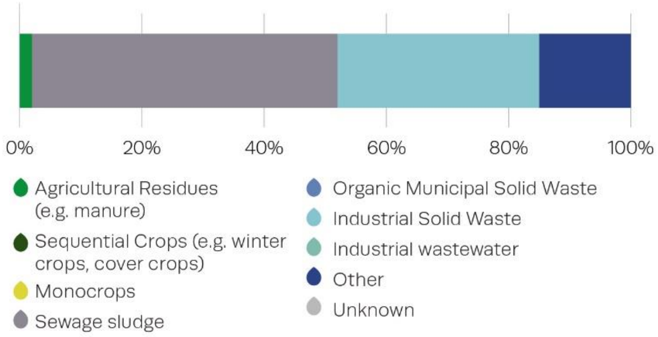

Figure 28 Digestate Sources in Austria

[51] EBA Statistical Report 2022

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Chapter 8: Overview of policy and financial framework, market status and production routes of renewable gases in Mission Innovation countries

8.1 Canada

8.1.1 Policy framework

Although Canada is the fourth largest producer of oil and the sixth largest producer of natural gas in the world (https://www.capp.ca/economy/canadas-oil-and-natural-gas-production/) they are also highly active in pursuing the target to develop renewable energy sources technologies, introduce them in everyday's life of Canadians and decrease their part of GHG contribution.

The following is a summary of targets established from the federal and provincial governments towards this direction:

- Utilities across Canada have agreed to renewable content targets for natural gas: 5% by 2025, 10% by 2030. Nevertheless, Canada does not have binding legislation to enforce these targets (https://www.cga.ca/natural-gas-101/the-renewable-natural-gas-opportunity/).
- In 2019, the Government of Québec introduced a renewable natural gas mandate that built on existing voluntary industry commitments. The regulation requires natural gas suppliers in the province to blend in a minimum 1% of renewable natural gas by 2020-2021 and a minimum 5% renewable natural gas by 2025-2026. In its 2020 climate plan the government indicates that plans to increase the renewable natural gas mandate further to 10% by 2030. Unlike the federal Renewable Fuels Regulations, a clear and predictable schedule for increasing minimum content requirements both optimizes the environmental benefits and the economic benefits of the regulation. (Copied in : https://biogasassociation.ca/news_and_events/entry/everything_you_need_to_know_about_a_renewable_gas_mandate)
- Ontario has set up the OptUp voluntary RNG program for residential customers: OptUp is an easy and affordable way to help green Ontario's NG supply. A 2$ a month contribution per residence is helping to fund the cost of purchasing and adding RNG to the present NG supply. The following schematic depicts the steps from organic waste to RNG delivered to residences and businesses.
- The British Columbia renewed policy allows up to 15% RNG in the total annual supply of natural gas. The recent changes enable natural gas utilities to increase the amount of Renewable Natural Gas (RNG), green and waste hydrogen, and other renewable energy they can acquire and make available to their customers (https://news.gov.bc.ca/releases/2021EMLI0046-001286).
- Other major suppliers have varying targets:

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- Enbridge: – 5% RNG by 2028 (https://www.reuters.com/business/sustainable-business/enbridge-inks-low-carbon-deals-with-shell-vanguard-renewables-2021-09-28/).
- FortisBC: 75% RNG by 2050 (https://www.fortisbc.com/build-renovate/builders-and-developers/renewable-natural-gas-for-buildings-and-developments).

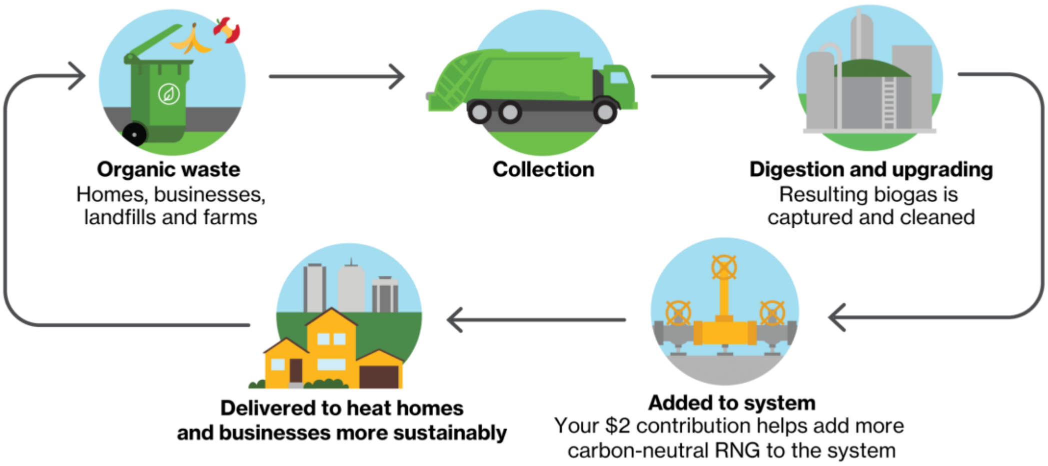

Figure 29. Production routes and end uses of biomethane in Canada (https://www.enbridgegas.com/sustainability/optup)

8.1.2 Financial mechanisms

The following programs are available for financing RNG technology development and uptake in Canada (https://biogasassociation.ca/resources/funding_and_incentives):

- **AGRICULTURAL CLEAN TECHNOLOGY PROGRAM**

It is a five-year, $3 billion investment by federal, provincial and territorial governments to strengthen the agriculture and agri-food sector. Federally-funded activities and programs to support sector growth focus on three key areas: Growing trade and expanding markets - $297 million; Innovative and sustainable growth in the sector - $690 million; and Supporting diversity and a dynamic, evolving sector - $166.5 million Federal program details and application forms are now available. It is not exclusive to RNG, but it includes it.

- **FEDERAL OUTPUT-BASED PRICING SYSTEM PROCEEDS FUND (OBPS)**

A program to support industrial initiatives that reduce greenhouse gas (GHG) emissions by deploying clean energy and clean technology. The OBPS is one of two elements under the federal carbon pricing system, along with the fuel charge on consumption. It covers facilities from heavy-emitting industrial sectors in provinces without a pricing system for industrial emitters. The program has two streams: the Future Electricity Fund and the Decarbonization Incentive Program. RNG falls within the latter.

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- **GREEN MUNICIPAL FUND ACCEPTING BIOGAS PROJECT PROPOSALS**

The Federation of Canadian Municipalities are accepting biogas project proposals through the Green Municipal Fund. Any communities that are interested in funding for a biogas project (or companies partnering with communities) can review funding opportunities on the FCM website.

- **TAX SAVINGS FOR CANADIAN RENEWABLE AND CONSERVATION EXPENSES**

Certain businesses and organizations have an accelerated capital cost allowance on certain types of eligible equipment. This credit aims to make renewable energy projects, including biogas, more attractive. The deduction rate obtained can go up to 50%, depending on the case.

- **QUÉBEC'S BIOMETHANATION AND COMPOSTING ORGANIC MATTER TREATMENT PROGRAM (PTMOBC)**

PTMOBC supports municipalities and businesses in the installation of infrastructures for biomethanation and composting of organic materials. It aims to reduce the amount of organic matter eliminated in Quebec and the GHG emitted during this process. The program started in 2009 and it has been extended until 2022. Projects are still underway. There is a possibility of further extension or a replacement by another program.

- **QUÉBEC'S RENEWABLE NATURAL GAS PRODUCTION SUPPORT PROGRAM (PSPGNR)**

The PSPGNR supports the development of RNG in Québec. The main features are: specific component for the financing of feasibility studies which allows subsidizing up to 75% of the cost incurred for, up to a maximum of $ 300,000 per project; the maximum level of financial assistance per RNG production and injection project into the natural gas distribution network increases from $ 8 million to $ 12 million; new eligible RNG production technologies; possibility for applicants to submit a preliminary draft in order to verify their eligibility for the PSPGNR; continuous assessment of submitted projects.

8.1.3 Market status

Canadian biogas projects, developed by farmers, municipalities and commercial private sector entities, are varied in size and type and predominately located in British Columbia, Alberta, Ontario and Québec. The following Table provides the Canadian installed capacity of RNG production (https://biogasassociation.ca/).

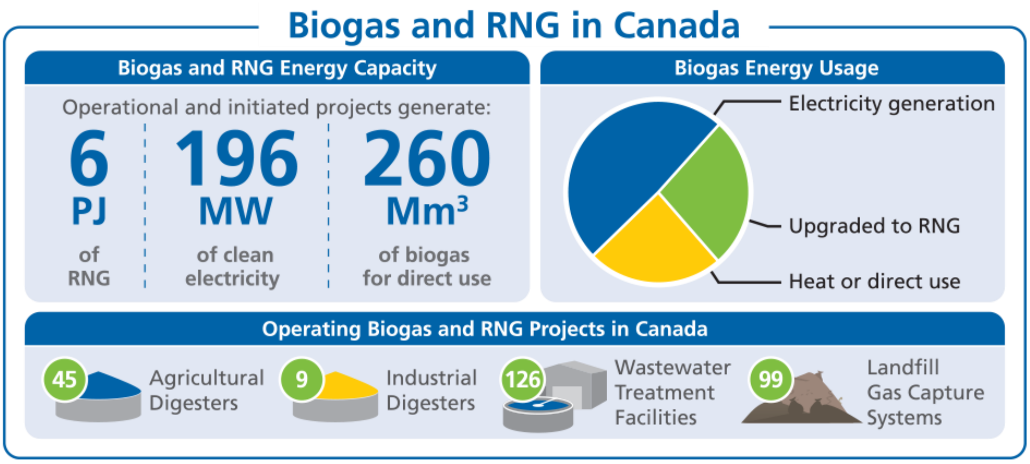

Figure 30. Market uptake of biomethane in Canada

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8.1.4 Production routes

General issues and R&D activities:

Biomethanization plants use anaerobic digestion to optimize the process of biomass degradation, in an oxygen-free and temperature-controlled environment: there are already units installed and operating across Canada and ongoing R&D to extend biomethanization on residual biomass (e.g. pulp and paper sludge; biomass steam-explosion residues and liquors). Hydrolysis, Acidogenesis, Acetogenesis and Methanogenesis are the four in-series (and parallel) steps taking place. They are subject of fairly intensive R&D activity to optimize the CH_4 yield. Various active bacterial biomasses are tested and the role of inhibitors is investigated.

Cleaning and purifying the captured biogas, mainly by removing heteroatoms impurities (i.e.; sulphur compounds) are used and are also subject to R&D endeavours.

Pyrogasification of biomass in the absence of oxygen with or without a subsequent catalytic conversion step produces a synthesis gas that can be converted into biomethane through catalytic processes.

Methanation is another route under development: this is achieved through catalytic hydrogenation of CO_2 obtained, for example, by purification of biogas.

Activities and projects:

The following biomethanization plants are already established in Québec or are in the process of building their facilities. Their achievements can inspire future regional or municipal projects:

- High throughput facility under construction (https://www.quebec.ca/en/agriculture-environment-and-natural-resources/energy/energy-production-supply-distribution/bioenergy/renewable-natural-gas) : For the treatment of organic materials, the City of Quebec has chosen biomethanation. The biomethanization center of the agglomeration of Quebec (CBAQ) will treat: food residues (86,600 t/yr); biosolids (materials from the wastewater treatment plant) (96,000 t/yr). The total capacity of the equipment will be 182,600 t/yr.
- Other projects (https://www.quebec.ca/en/agriculture-environment-and-natural-resources/energy/energy-production-supply-distribution/bioenergy/renewable-natural-gas)
    - Centre de traitement de la biomasse de la Montérégie
    - Coop Agri-Énergie Warwick
    - Projet de biométhanisation in the city of Saint-Hyacinthe
    - Centre de biométhanisation in the agglomeration of Québec

More information can be obtained in the review by Gowling WLG in the following site: https://gowlingwlg.com/en/insights-resources/articles/2021/canadian-biogas-advancements-and-opportunities/

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8.2 China

8.2.1 Policy framework

China has announced that wants to be carbon neutral by 2060. To achieve this goal, the government has implemented a series of policy measures, as described below:

The existing policies to promote biomethane industry are as the following:

- Notice on Further Improving the Consumption of Newly Increased Renewable Energy not Included in the Control of Total Energy Consumption issued by National Development & Reform Commission, National Bureau of Statistics, etc. in November 2022.
- Energy Carbon Peak & Carbon Neutral Standardization Improvement Action Plan issued by National Energy Administration in October 2022.
- The "Fourteenth Five-year Plan" Bio-economy Development Plan issued by National Development & Reform Commission in May 2022.
- "Opinions on Accelerating the Implementation of Rural Energy Transformation to Help Rural Revitalization"issued by National Energy Administration, Ministry of Agriculture & Rural Affairs, National Rural Revitalization Bureau, in December 2021.
- Opinions on Deepening the Tough Battle against Pollution issued by the Central Committee of the Communist Party, the State Council in November 2021.
- Opinions on Deepening the reform of the Compensation System for Ecological Protection issued by the General Office of the CPC Central Committee, the General Office of the State Council, in September 2021.
- Opinions on Comprehensively Promoting Rural Revitalization and Accelerating Agriculture and Rural Area Modernization issued by the Central Committee of the Communist Party , the State Council, in January 2021.
- Guiding Opinions on Promoting the Development of Bio-natural gas Industrialization. Issued by NDRC and other nine ministries on 4 Dec. 2019, including:
    - Incorporating bio-natural gas into the energy management system, and formulate policies and measures for the priority use of bio-natural gas.
    - Implementing relevant preferential policies such as land, tax revenue and electricity prices.
    - The target is 10 billion cubic meters in 2025 and 20 billion cubic meters in 2030.
- Strategic Planning for Rural Revitalization. Issued by State Council on 26 Sept. 2018, including:
    - Accelerating large-scale bio-natural gas and large-scale biogas projects.
- The Opinions of the CPC Central Committee and the State Council on Comprehensively Strengthening Ecological and Environmental Protection and Resolutely Fighting the Hard Battle against Pollution. Issued by State Council, including:
    - Implementing bio-natural gas projects
- Opinions of the General Office of the State Council on Accelerating the Transformation of the Agricultural Development Mode. Issued by State Council on 3 Dec. 2017, including:
    - Promoting the integrated development model of large-scale livestock and poultry breeding, biogas production.

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  - Integration of accumulation and manufacturing of organic fertilizer from farm manure.
- Opinions of the General Office of the State Council on Accelerating the Resource Utilization of Livestock and Poultry Breeding Waste. Issued by State Council on 3 May 2017, including:
  - To strengthen fiscal and tax policy support:

    to build large-scale bio-natural gas projects and large and medium-sized biogas projects;

    to implement the policy of benchmark electricity price selling to grid for biogas power generation and full guaranteed purchase of electricity, and lower the threshold for single-alone power generation;

    the bio-natural gas meets the technical standards for the network, the enterprise operating in the gas pipe network should accept it into the network;

    to implement the policy of collecting and withdrawing value-added tax on biogas and bio-natural gas, and support bio-natural gas and biogas projects to carry out carbon trading projects.

- To solve land use problems as a whole:

  large-scale bio-natural gas projects and large-scale biogas projects with livestock and poultry breeding waste as the main raw materials will be included in the overall land use plan, and priority will be given in the annual land use plan.

- Guidance on Strengthening the Construction of Rural Biogas Service System. Issued by Agriculture and Rural Affairs on 20 May 2009, including:
  - to accelerate the formulation of a new round of rural biogas project construction plans, to completed the retraining of 210,000 workers in biogas plants to improve the professional quality of relevant practitioners and ensure the service effect.
  - to carry out pilot projects of centralized straw biogas supply, and increase the promotion of straw biogas.
  - to promote the construction mode of joint household biogas and centralized gas supply in breeding communities and large-scale livestock and poultry farms, and actively promote the construction of large and medium-sized biogas plants.

8.2.2 Market status

300 million Nm3 biomethane were produced in 2022 to contribute 0.0892% of natural gas consumption. 3.7 billion Kwh biogas power generation contributed to 2.3% of biomass power production, and biopower contributed to 2% of China's electricity consumption.

According to the Development Plan of Bio-Natural Gas issued by NDRC, 10 billion cubic meters biomethane will be produced by 2025, and 20 billion cubic meters by 2030.

Biomethane production potential from agricultural waste, urban organic waste, and industrial waste water is round 300 billion cubic meters.

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Continuous solid state anaerobic fermentation is a promising technology, and at pre-commercialization stage.

Biomethane carbon monooxide reforming to produce syngas as the feedstock to produce sustainable aviation fuel (SAF) is a new option of biogas utilization.

8.2.3 Production routes

At present there is transition from house-hold biogas tank for farmers'family use to industry-based anaerobic digester for bio-natural gas production.

There are more than 40 million house-hold biogas tanks to produce around 17 billion Nm3 biogas for improving farmers'energy use.

There are more than 100,000 industrial digesters to produce around 3 billion Nm3 biogas for power generation and biomethane production. 300 million Nm3 biomethane were produced to be injected to natural gas pipeline or for vehicle use annually .

Liquid state anaerobic fermentation is the dominant technology, and waste water is one of the biggest issues for biogas and biomethane production.

The production efficiency of batch solid state anaerobic fermentation is poor, hence there are only a few plants using solid state fermentation technology.

Since most bio-natural gas plants are not profitable, the infant industry is at a dilemma state.

8.3 India

8.3.1 Policy framework

There were two major plans to support biogas/biomethane: the Gobardhan for biogas support and the SATAT – Sustainable Alternative to affordable transportation for supporting transportation.

More specifically, the Government of India proposed a new scheme called Sustainable Alternative Toward Affordable Transportation (SATAT) in 2018 (Ministry of Petroleum Natural Gas, GOI, 2019).

The scheme facilitates setting up Bio-CNG plants based on available residues/wastes, and ensures that the Bio-CNG thus produced will be marketed by the oil marketing companies as transport fuel through long term purchase agreements. The target is to set-up 5000 biogas plants producing 15 MMTPA (Million Metric Tonnes per Annum) by 2025-26. These plants will also produce 90 MMTPA of fermented organic manure, which can be sold as a fertilizer providing additional source of income for these plants. For 2023-24, 500 plants are to get fiscal incentives and 100 % off take guarantee by OMC's companies. The pipe line injection of CBG has given a big push to connect biogas plants and CNG, with priority lending by Public sector banks. 3300 Letters of Interest and 2400 MoU are signed – 40 Commissioned Most of the 2 and 3 wheelers will run on Compressed BG or E100 after 2025 besides already existing CNG vehicles.

As per the SATAT scheme, the CBG price is being set at $0.62 (INR 46)/kg (without taxes) at the fuel dispensing station. The scheme offers a financial subsidy of $ 0.54 Million (INR 4 crores) for

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a plant with a Bio-CNG capacity of 4.8 tonnes per day, with a maximum subsidy of 1.34 Million $ (Rs.10 cores) per project (IOCL et al., 2018).

8.3.2 Market status

Biogas has been considered as a renewable fuel sources for many decades in India. The initial interest was in using cow dung to produce biogas in small scale set-ups and use it for domestic applications such as cooking. It is reported that around 5 million family biogas plants have been established under the biogas development program. Most of these plants would be relying on cow dung as the feedstock. The total potential though is for 12 million plants.

The transport sector, however, is generating a lot of excitement in recent times in the biomethane sector. India is aggressively pursuing a transition towards a sustainable and greener transport sector. CNG (compressed natural gas), being a cleaner fuel, is already playing a major role in cities like New Delhi where public transport vehicles must run on CNG. However, much of India's transport sector CNG requirement is being met through imports of liquified natural gas (LNG). Thus, although local pollution is being reduced through the adoption of CNG, the country's import dependency is increasing while also raising concerns about the net climate change impacts due to long-distance imports. India is also simultaneously grappling with the issue of management of excess agricultural residue. Current practices are highly unsustainable and include the burning of residue resulting in severe local and regional pollution. In this context,

8.3.3 Production routes

The use of biogas produced from cow dung and agricultural residues is also proposed to be used in industrial heating and power applications. Around 400 off-grid power plants based on biogas have been set-up with a total capacity of 5.5 MW. For the medium to large scale plants, agricultural residue is an important feedstock. In particular, sugar industry has been using waste streams generated in sugar mills such as spent wash and press mud as feedstock for anaerobic digestion. This provides them with an option to generate in-house power, as well as taking care of the waste that is generated.

Ensuring continuous operations of these biogas plants though has been a matter of concern. It is reported that out of the 5 million small scale plants, 55% are either not fully functional or not functioning at all. Even in the power sector, only 56 out of about 400 plants have been reported to be functional. A number of factors have been responsible for this, including lack of monitoring and supervision, overdesign of digesters, variation in the quality and quantity of feedstock, and non-availability of technical expertise for repairs.

Recently, anaerobic digestion of municipal solid waste to produce biogas has also generated a lot of interest. The technologies include floating drum with cylindrical digester (KVIC model), fixed dome with hemispherical model (Deenbandhu model), as well as the Nisargruna model developed by BARC. The gas upgradation technologies are generally not implemented since they are expensive.

In terms of biogas production, the existing technologies can be used in the context of SATAT scheme as well. However, since the CBG produced has to meet specific standards (IS 16087: 2106), biogas upgradation (separation and purification) becomes an important part of the

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system. Different options such as such as water scrubbing and membrane separation are being considered for implementation.

8.4 USA

8.4.1 Policy framework

- **Federal Policy**

The top U.S. federal policies designed to promote the production and use of RNG are the U.S. Environmental Protection Agency's Renewable Fuel Standard and tax credits created by the recent Inflation Reduction Act.

Renewable Fuel Standard – The United States Environmental Protection Agency's Renewable Fuel Standard (RFS) requires petroleum producers and importers to subsidize the production and use of a certain amount of renewable fuel each year. The program incents a range of biofuels, including traditional renewable fuels (e.g., ethanol and biodiesel), as well as RNG, and will likely be amended to include biogas- and RNG-to-electricity. Broadly speaking, this policy works as a renewable portfolio standard for the U.S. transportation sector.

Inflation Reduction Act – The Inflation Reduction Act was enacted by U.S. congress in 2022 for the purpose of providing tax credits to a wide range of renewable energy and other clean technologies. More information is included in the "Financial Mechanisms" section below.

- **State Policy**

The top state policies designed to promote the production and use of RNG are the low carbon fuel standard, renewable gas standard, and clean heat standard. There are many examples of these policies in development or consideration throughout the U.S. and Canada; the most prominent examples of which are listed in this section.

Low Carbon Fuel Standard – The low carbon fuel standard (LCFS, also known as a clean fuel standard) is a technology-neutral policy which sets a declining carbon intensity (CI) target on a state's transportation sector; essentially a form of renewable portfolio standard. Inevitably, cleaner fuels and other technologies (e.g., electrification) will be needed to reach the programs targets as the CI requirement declines over time. The lifecycle CI of each transportation fuel pathway (including electricity) is calculated; credits and deficits are generated by comparing each fuel's CI relative to the CI target each year. RNG receives significant credit under this framework where methane reductions are achieved in the organic waste sector. Credits must be procured by entities which sell fuels above the CI baseline for each year.

California has the most prominent example of a low carbon fuel standard.[52] Its low carbon fuel standard rewards GHG emission savings enabled by biomethane production, including the so-called "negative emissions" (most notably achieved, when a significant proportion of manure is used in the anaerobic digestion process). Lifecycle emissions of each RNG production plant are registered in the national "GREET" system, providing a project-specific emission accounting valuing the performance of individual production plants. The Californian crediting scheme use the GREET system as a source for GHG emission savings and GHG emission credit certificates.

[52] https://ww2.arb.ca.gov/our-work/programs/low-carbon-fuel-standard

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With respect to RNG, California has achieved nearly 100% RNG use in its natural gas vehicle sector. Notably, these programs stack with the federal RFS, providing a strong incentive.

The following is a map of state-level low carbon fuel standards in North America:

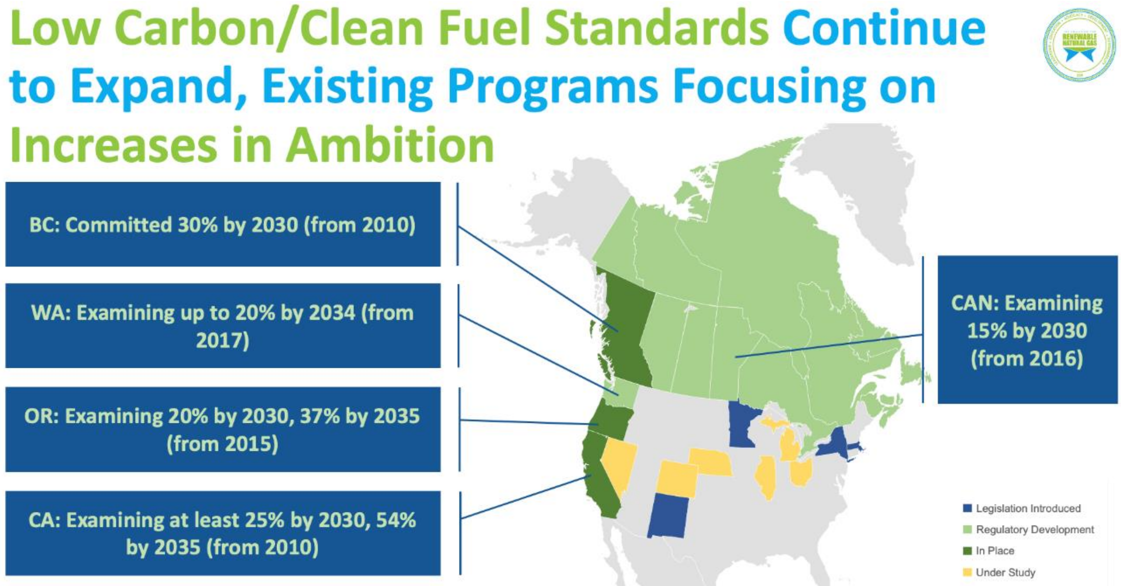

Figure 31.

Renewable Gas Standard – The Renewable Gas Standard (RGS) is a renewable portfolio standard policy which specifically targets gas supply in a given jurisdiction. These policies are typically designed with benchmark targets over time, reaching a high target at the end of the program's life, often based on estimated supply potential and/or carbon reduction goals. California has the most prominent example of a RGS in the U.S.[53]

Clean Heat Standard – The Clean Heat Standard (CHS) is a renewable portfolio standard policy which specifically targets heating in a given jurisdiction, similar to an RGS, but with a broader technology allowance. For example, a CHS may include renewable gas, electrification, geothermal, and other decarbonization measures. Minnesota has the most prominent example of a CHS in the U.S.,[54] although it should be strengthened with the addition of specific emission reduction targets.

The following is a map of state-level renewable gas and clean heat standards in North America:

[53] https://www.cpuc.ca.gov/news-and-updates/all-news/cpuc-sets-biomethane-targets-for-utilities
[54] https://mn.gov/puc/about-us/news/archives/?id=14-509751

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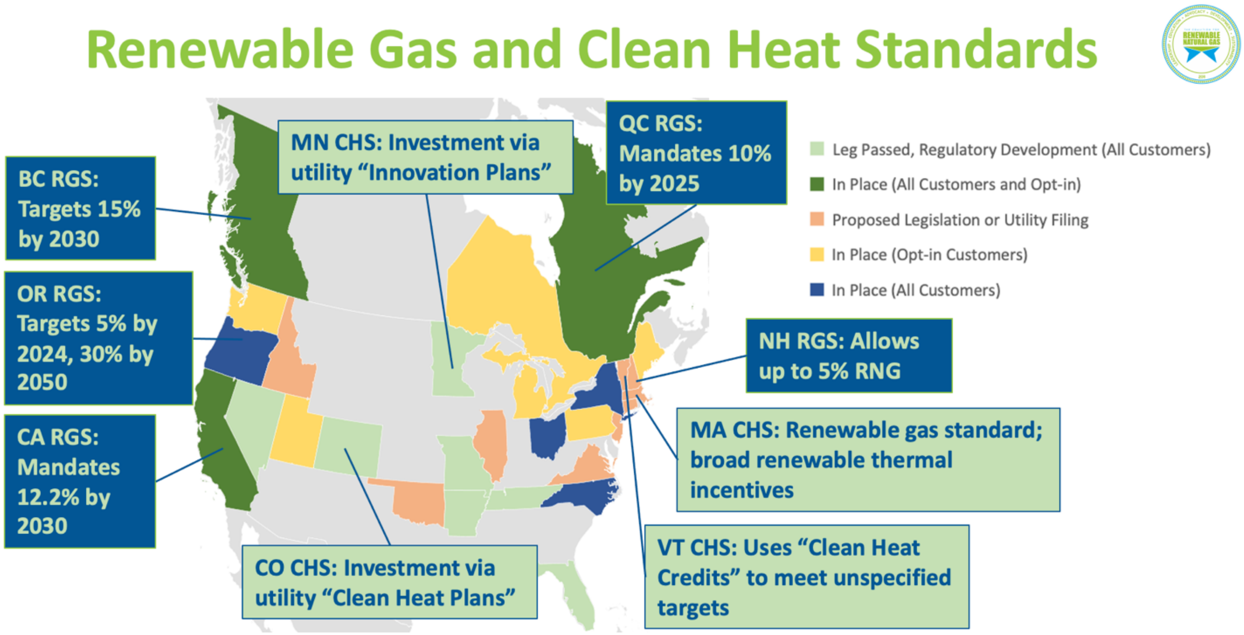

Figure 32. State-level renewable gas and clean heat standards in North America

8.4.2 Financial Mechanisms

The primary financial mechanisms designed to support RNG and biohydrogen production in the U.S. are the tax incentives provided by the *Inflation Reduction Act.* The U.S. Treasury Department has not yet provided guidance on specific qualifications, however, we expect the following tax credits to have a substantial impact on our industry:

- Biogas property, including cleaning and conditioning equipment, as qualifying equipment for purposes of the Section 48 energy credit
- Extension of $.50 alternative fuel tax credit
- New technology neutral clean hydrogen tax credit which allows for the use of RNG and other biomass inputs as qualifying feedstocks
- 45Q carbon oxide sequestration credit

Other state-level grant programs may also exist which support the use of RNG. For example, California's Dairy Digester Research & Development Program[55] has supplied significant funding for the buildout of biogas and RNG resources in the state.

8.4.3 Market status

The following are a map of RNG facilities in North America based on RNG Coalition's facilities database;[56] a graph showing the increase in RNG facilities over time; and a current breakdown of RNG production by feedstock. Note that a significant increase in RNG facilities occurred when RNG became incentivized under the RFS and California's LCFS programs in the 2010's.

[55] https://www.cdfa.ca.gov/oefi/ddrdp/
[56] https://docs.google.com/spreadsheets/d/1CpLTd1Yya4qQzUpWYtKMUGW1BlMmn-Jrj3uErd8lJ7A/edit#gid=0

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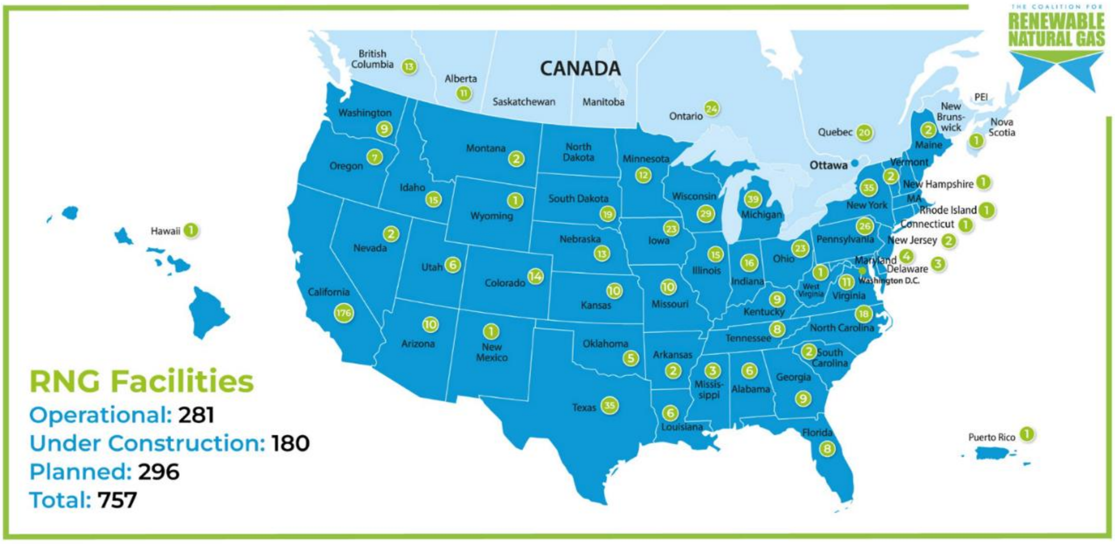
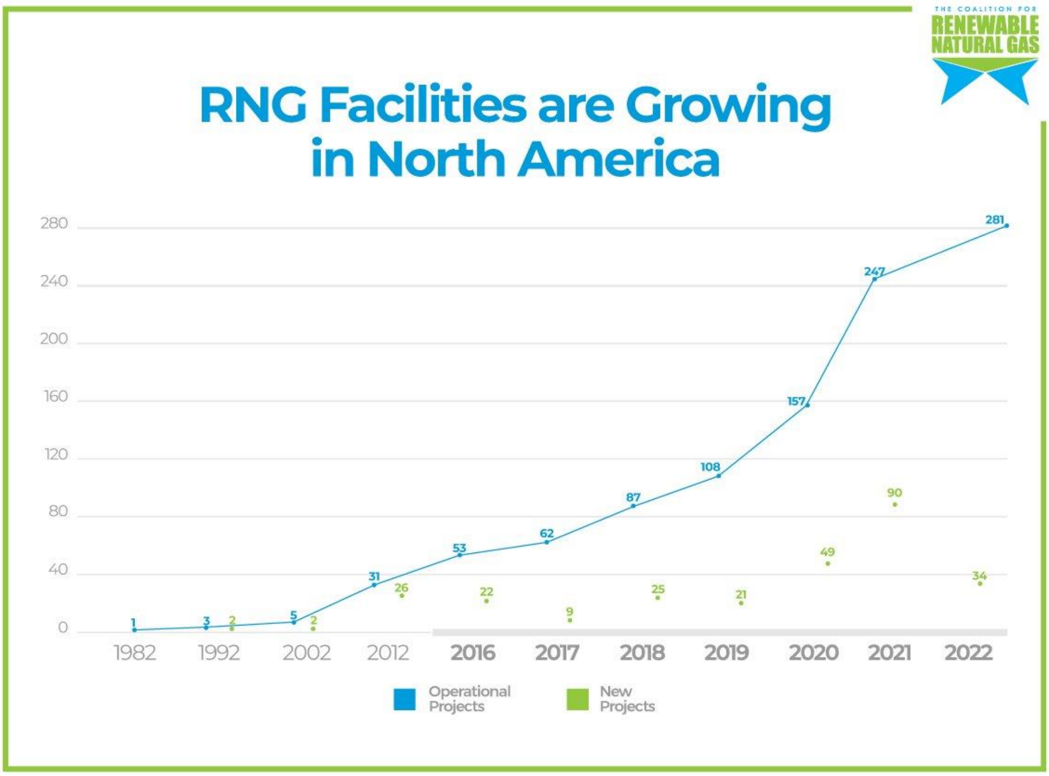


Figure 33. RNG facilities in North America



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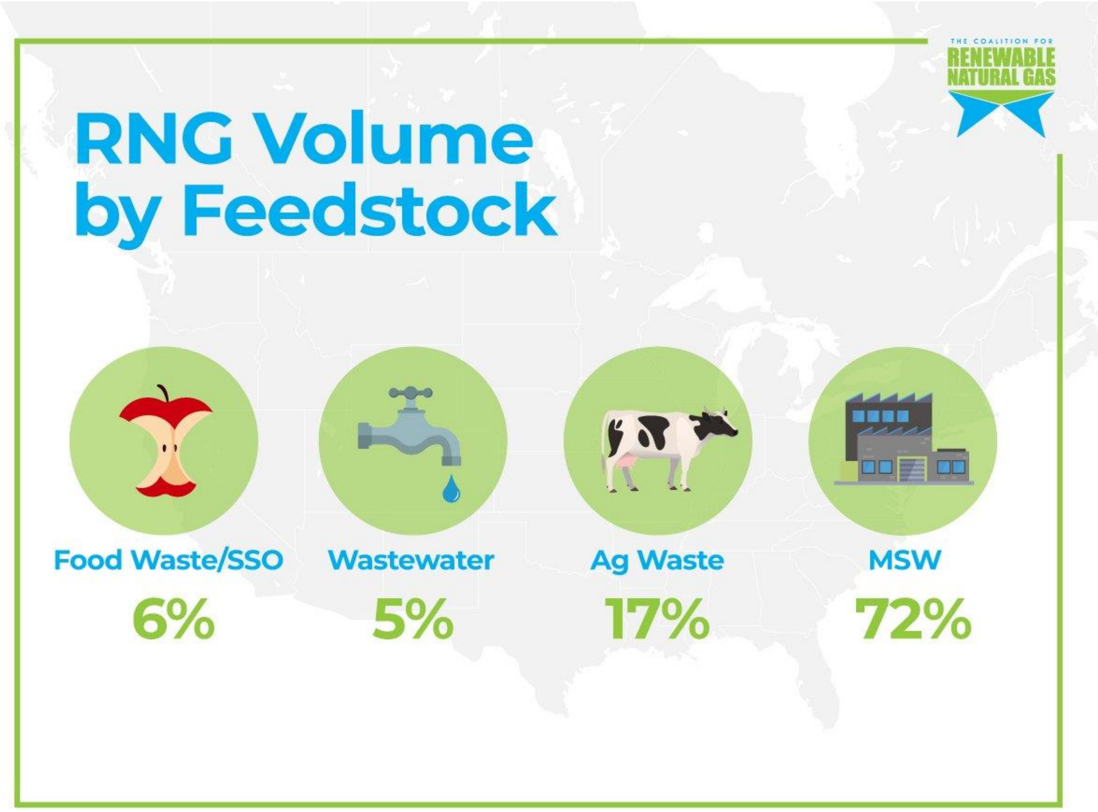

Current estimated RNG production from anaerobic digestion (AD) feedstocks[57] in North America can be broken down as follows:

Operational – 93.37 tBtu/yr

Under Construction – 31.12 tBtu/yr

Planned – 44.18 tBtu/yr

Comparatively, projections from consulting firm ICF[58] show that our industry can supply 1,425.3-4,300 tBtu/yr from AD feedstocks by 2040. This is equal to 9-26% of combined 2021 residential, commercial, and industrial natural gas demand in the U.S.[59] Non-AD feedstocks (for example, other forms of agricultural or forestry waste suitable for gasification) can achieve additional RNG or hydrogen production, but are not being used at commercial scale in the U.S. at this time.

It is important to note that most RNG is currently used in the transportation sector. However, much of the current policy development is aimed at promoting RNG use in other sectors, such as heating.

[57] Including landfill gas, wastewater, animal manure, and food waste.

[58] https://static1.squarespace.com/static/53a09c47e4b050b5ad5bf4f5/t/633232e43e255c03bafe1c40/1664234232436/AGF-2019-RNG-Study-Full-Report-FINAL-12-18-19.pdf

[59] https://www.eia.gov/dnav/ng/ng_cons_sum_dcu_nus_a.htm

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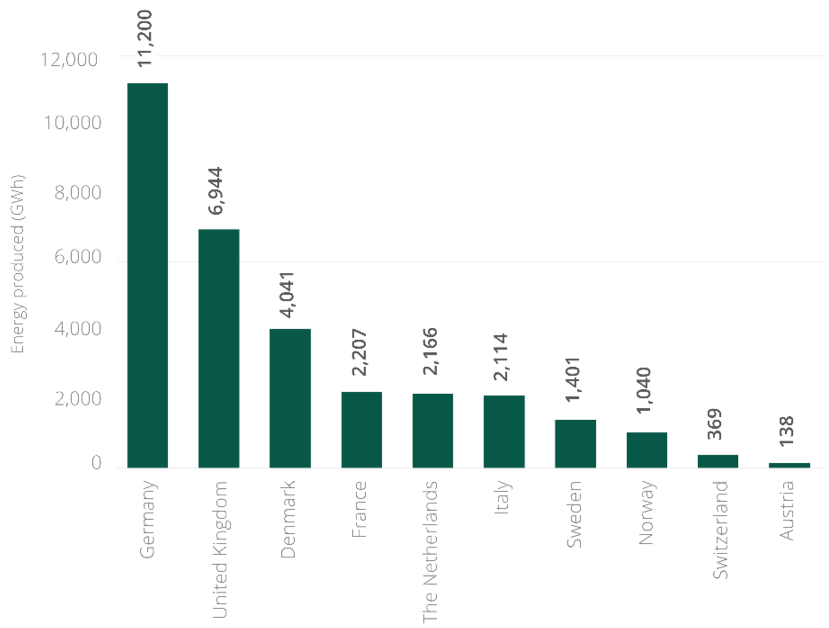
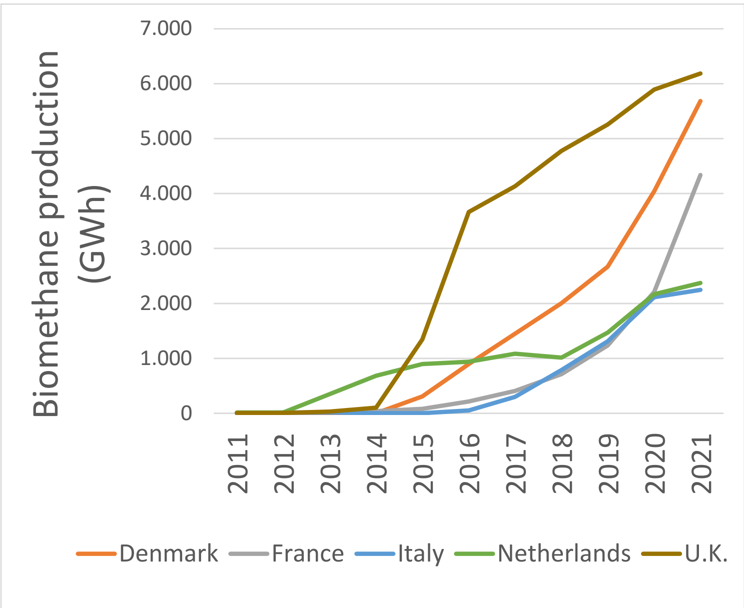
Annexes

Biomethane production in the 10 selected European countries

Graph 1: Biomethane production in 2020 per country in descending order (GWh), top 10 countries



Graph 2: Biomethane production growth in the 5 soaring European biomethane markets, each having different take-off years (2011-2021)



Based on the database of the European Biogas Association.

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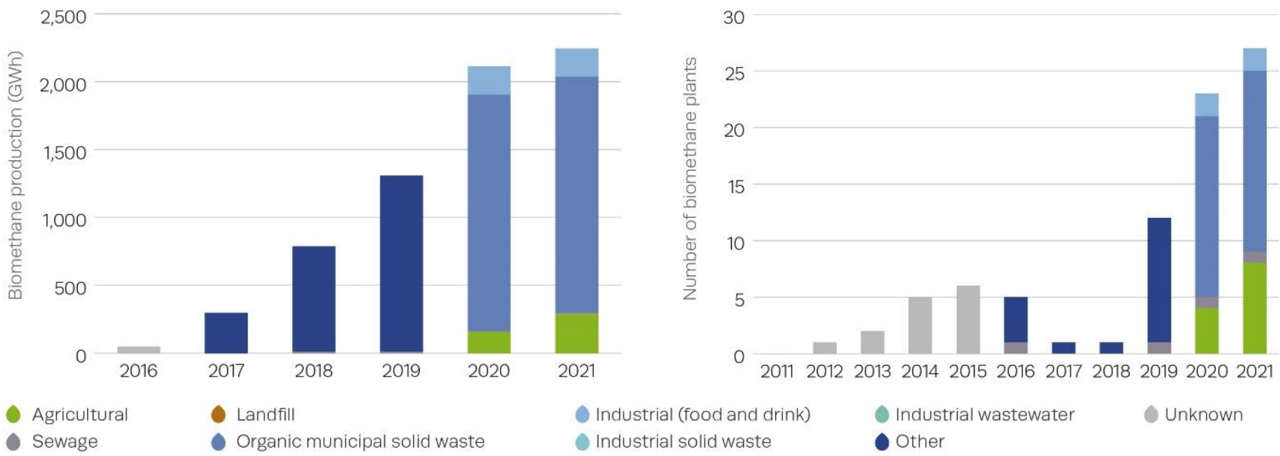
Graph 3: Biomethane production growth in Germany (2011-2021)

European Biogas Association, Statistical Report 2022

Graph 4: Biomethane production growth in Italy (2011-2021)



European Biogas Association, Statistical Report 2022

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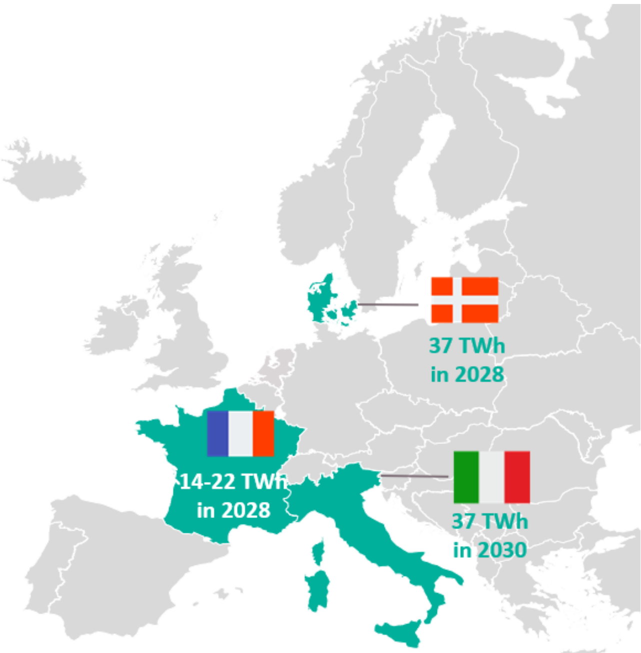
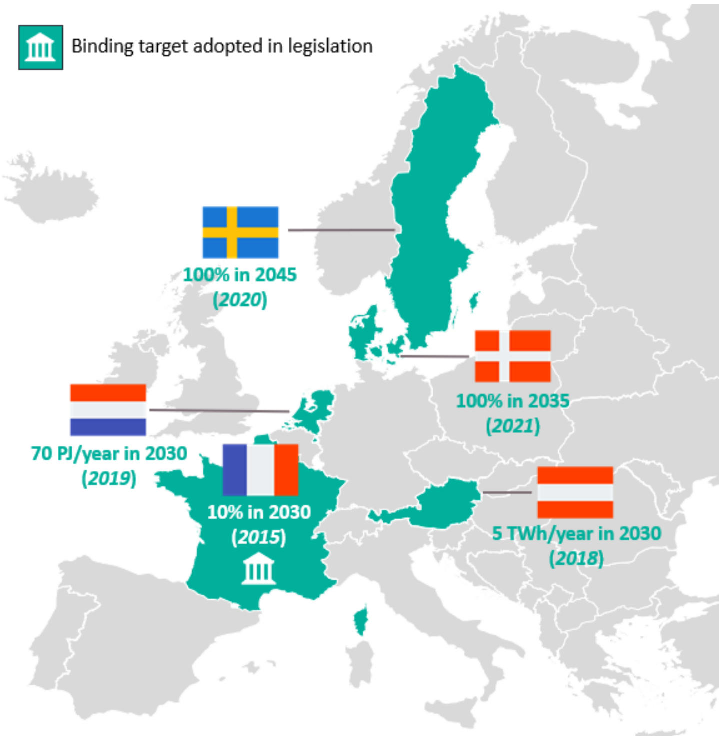
Map of official biomethane targets (2011-2021)



Official targets of biomethane production adopted in the 10 "advanced countries" in the period 2011-2021

Map of official renewable gas targets (2011-2021)



Official targets of renewable gas consumption or production (year of adoption) adopted in the 10 "advanced countries" in the period 2011-2021

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