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Biomethane Production and Grid Injection: German Experiences, Policies, Business Models and Standards

Sino-German Energy Partnership

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Imprint

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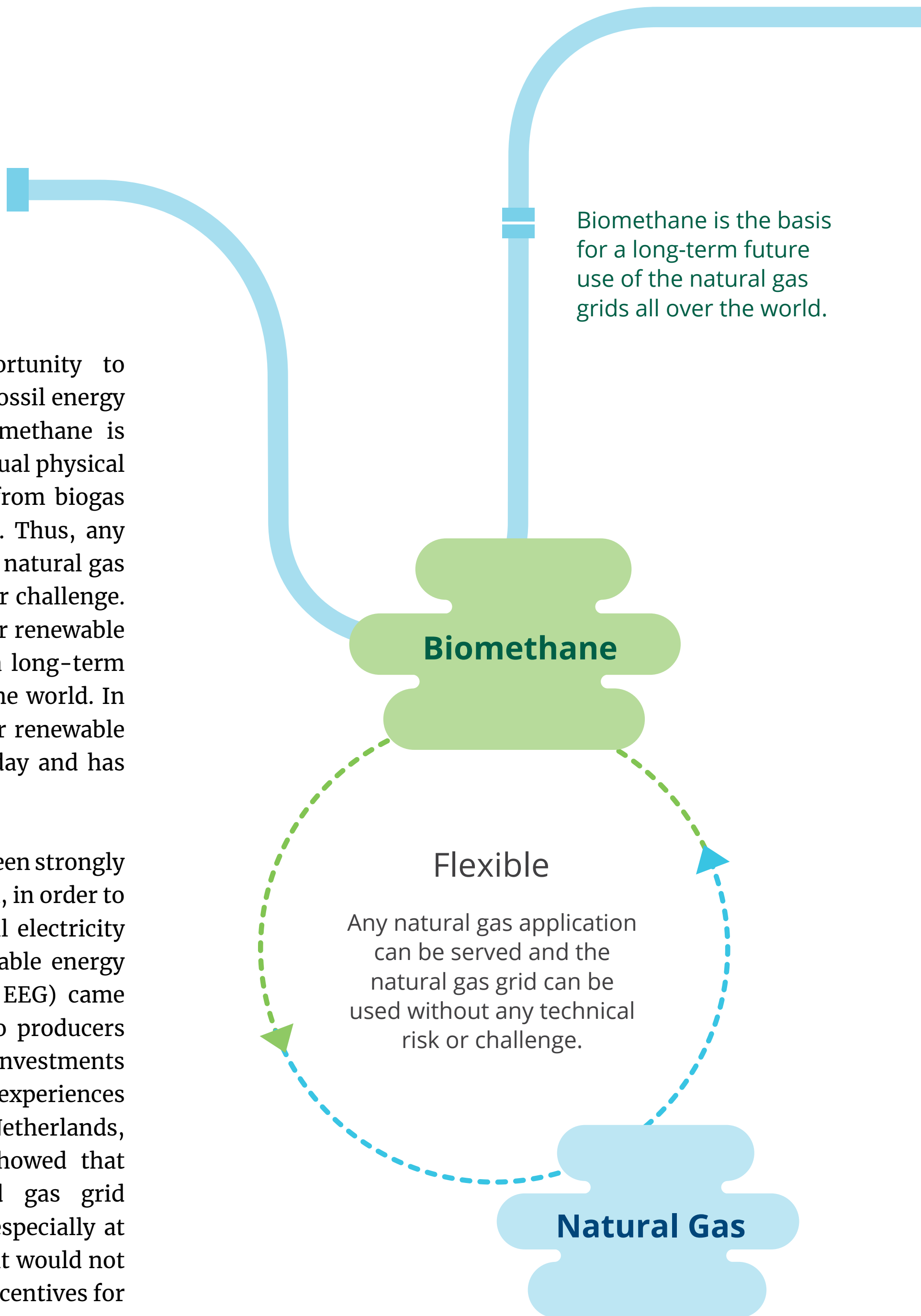
List of Abbreviations

EEG	Erneuerbare Energien-Gesetz (EEG, Renewable Energies Sources Act)
CHP	Combined Heat and Power (Unit)
CNG	Compressed Natural Gas
LNG	Liquified Natural Gas
ORC	Organic Rankine Cycle
RED II	Renewable Energy Directive II
GHG	Greenhouse Gases
BTL-FTD	Biomass-to-Liquid by Fischer-Tropsch Process
FAME	Fatty Acid Methyl Esters
HVO	Hydrotreated Vegetable Oils
NGV	Natural Gas Based Vehicle

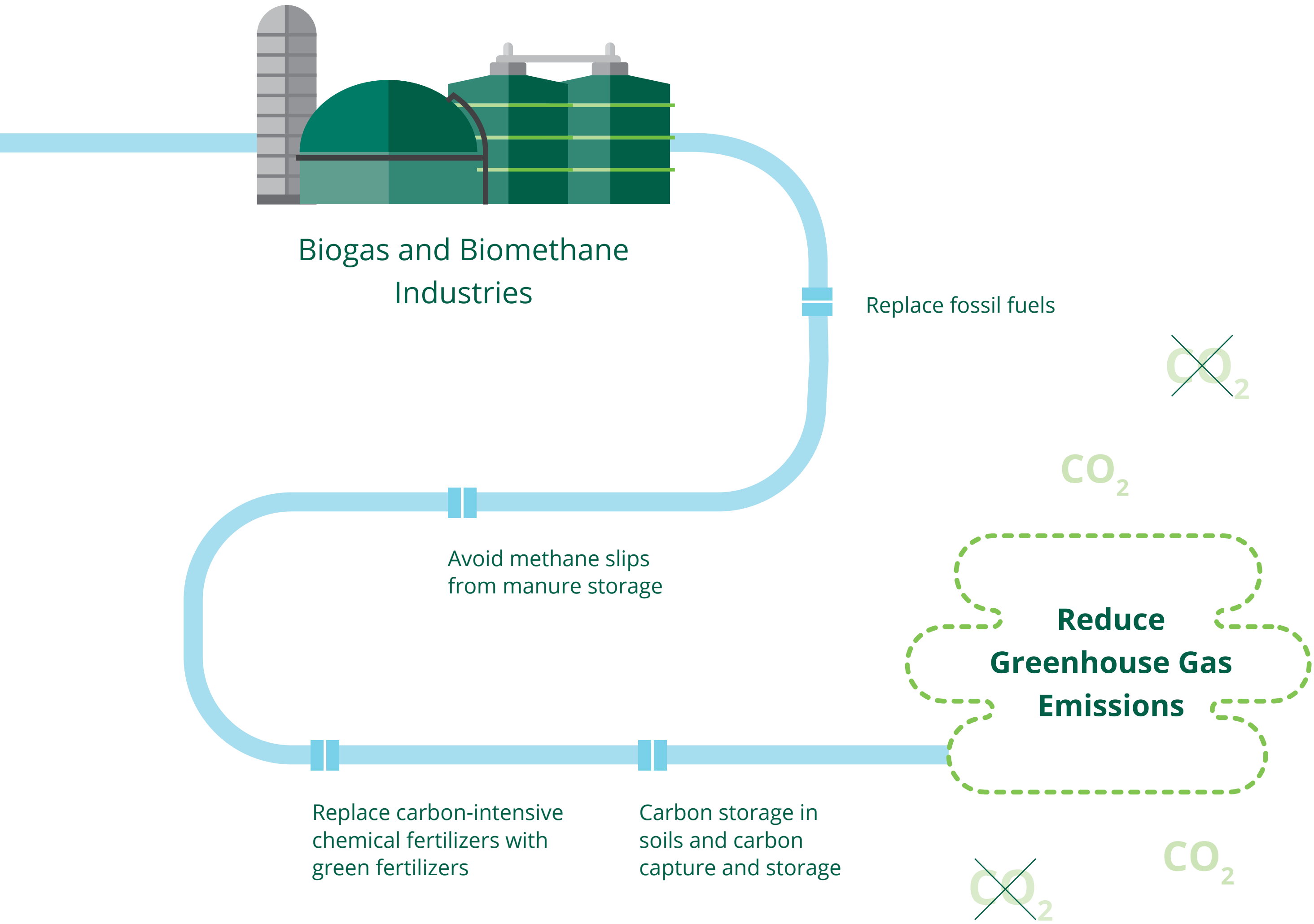
1

Introduction



Biomethane offers the outstanding opportunity to substitute fossil natural gas as well as other fossil energy carriers in an extremely flexible way. Biomethane is interchangeable with natural gas – having equal physical and burning characteristics. It is produced from biogas by upgrading the gas to natural gas quality. Thus, any natural gas application can be served and the natural gas grid can be used without any technical risk or challenge. Biomethane – in close conjunction with other renewable gases, such as hydrogen – is the basis for a long-term future use of the natural gas grids all over the world. In addition, biomethane is – compared to other renewable gases – a technology, which is available today and has been tried and proven for more than 20 years.

In Germany, renewable energy sources have been strongly promoted for electricity generation since 1991, in order to reduce greenhouse gas emissions from fossil electricity production. In 2000, Germany's first renewable energy sources act (Erneuerbare-Energien-Gesetz, EEG) came into force, which provided feed-in tariffs to producers of electricity from biogas and in turn made investments into biogas plants attractive. Based on experiences from Sweden, Switzerland and the Netherlands, biogas upgrading to natural gas quality showed that decentralised biomethane production and gas grid injection allows for flexible use of the gas, especially at locations where construction of a biogas plant would not be possible, e.g. in town centres. Therefore, incentives for biomethane production were introduced for the first time in 2004 – in the first years for combined heat and power production (CHP) use only, later for use as vehicle fuel and for heating purposes.



Based on the ambition of the German government and the European Commission to strive for climate-neutrality towards 2050, renewable gases with low greenhouse gas (GHG) emission values are being supported in order to substitute fossil gases in the gas grids. Moreover, gas transport in the grid has much lower energy losses when compared with electric power transmission. This reflects the fact that energy transportation will be an increasing challenge in a 100% renewable energy system of the future, e.g. when wind energy must be transported from the coast into industrial areas. The biogas and biomethane industries are significant and growing contributors to achieving climate-neutrality by 2050. As calculated by the World Biogas Association, the sector has the potential to reduce worldwide GHG emissions by 10-13% (World Biogas Association, 2019). The biogas and biomethane industries reduce emissions via many different pathways, such as avoided emissions with the replacement of fossil fuels, avoided methane slips from manure storage, replacement of carbon-intensive chemical fertilizers with green fertilizers, carbon storage in soils and carbon capture and storage.

Nowadays, there are still huge potential amounts of biomass available from agricultural, industrial and municipal wastes, for which there is no better use than biogas production and conversion of the biomass into valuable fertilizer.

2

What is biomethane?

Biomethane typically starts out as biogas. Biogas is one of the outputs of anaerobic digestion of biomass and contains around 55 to 60% methane (CH_4) and 40 to 45% carbon dioxide (CO_2) along with other trace gases (including water vapour and sulphur dioxide, SO_2). Biogas upgrading is the process of removing the CO_2 from the gas mixture resulting in a final product with a CH_4 content of at least 90%. Depending on the quality of the biomethane, it can be used in natural gas applications and/or fed to the public gas grid, which today mainly serves for transporting natural gas.

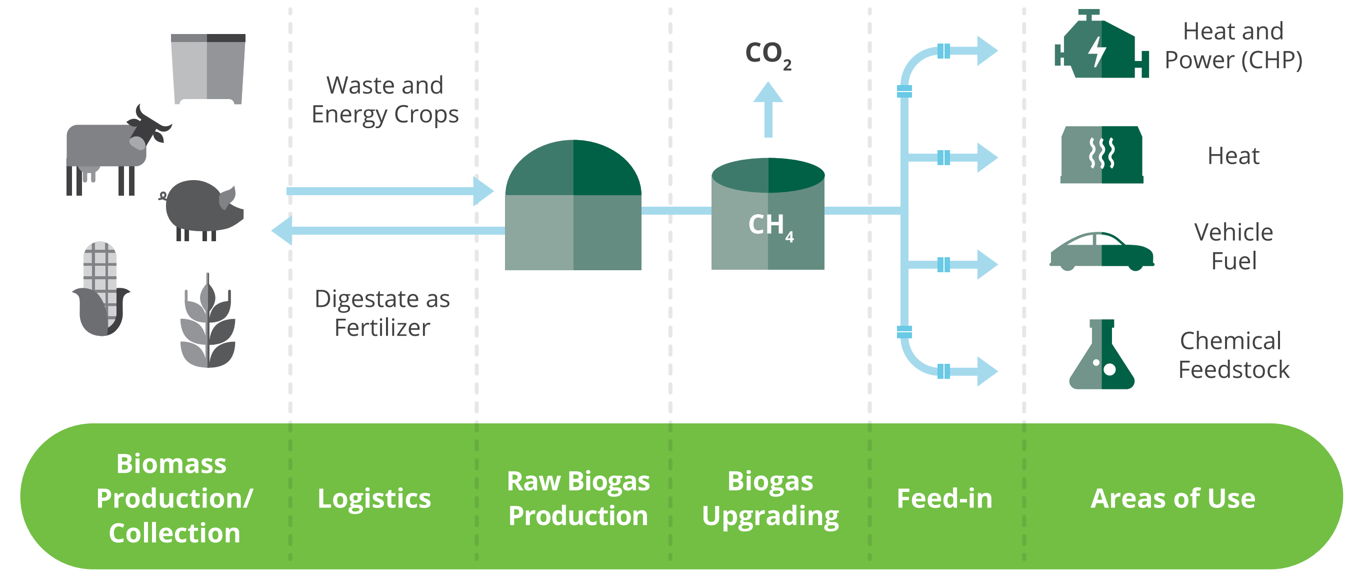
Biogas can be produced at a biogas plant from a wide range of different organic substrates. In Germany, the substrates are generally in one of the following categories:

- Energy crops
- Manure
- Municipal organic waste
- Industrial and commercial organic waste
- Vegetable residues from agriculture
- Wastewater with high organic content, such as sewage sludge or residues from industrial processes

There are different kinds of biogas reactors, which have been developed specifically for the different substrates. Wastewater requires very different equipment due to the extremely high water content. For municipal and industrial/commercial organic waste there are several plant types available, which are chosen based on different factors, such as the water content and impurities (e.g. plastic bags used for garbage collection). Biogas plants, which use energy crops, manure and agricultural residues as the main substrates, are generally the most standardized plants in Germany since the substrates have a relatively stable quality.

As can be seen in Figure 1 biomethane can be used in several applications. A combined heat and power (CHP) unit can be used for the production of electricity and heat. This is especially beneficial and efficient in areas with a high heat demand – ideally throughout the year, e.g. heating of buildings or process heat in industries. Biomethane can also be used as a fuel in vehicles, which run on compressed natural gas (CNG) or in heat-only applications, such as boilers for delivering heat to buildings or industrial processes. A relatively new pathway of using biomethane is its application for material use, e.g. in the chemical industry, where products, based on natural gas can be replaced by biomethane.

Figure 1: Value supply chain for a biogas plant.



After the biomass has been digested in the biogas plant it leaves as a product called digestate. The digestate can be used in agriculture as a substitute for mineral fertilizers, since the nutrients are retained throughout the biogas production process. Moreover, they contribute to build-up humus and structure in the soil. The use of the digestate closes the nutrient cycle.

Based on estimations of the German Biogas Association some 128 million tonnes of digestate are produced annually in the 13,000 biogas plants in Europe. For Germany, no exact numbers are available, but it can be estimated to be around 80 million tons of digestate annually, which are used as fertiliser. Most digestate is used without further treatment, transported in tanks to the fields during the seasons during which the field crops are able to take up the contained nutrients. Technologies with low ammonia emissions are used to spread the digestate (mostly drag hoses, sometimes injection with slitters into the soil). At many biogas plants logistics and storage optimisation takes place using solid-liquid separation technologies (e.g. screw press or centrifuges) to produce a solid fraction and a liquid fraction for better handling. Further treatment is connected with high cost, but the following technologies can be found at several biogas plants in Germany.

- Drying / Evaporation
- Pelletising
- Biological treatment
- Liquid preparation
- Nutrient extraction

Additional insight into digestate utilisation and treatment is given by the German Biogas Association, see Further Reading.

Spotlight

1

Valuable products resulting from or compatible with biogas production

Biogas plants are not merely renewable energy production plants. Aside from methane the fermentation process produces capturable CO2 and a substitute for synthetic fertilizers.

Digestate

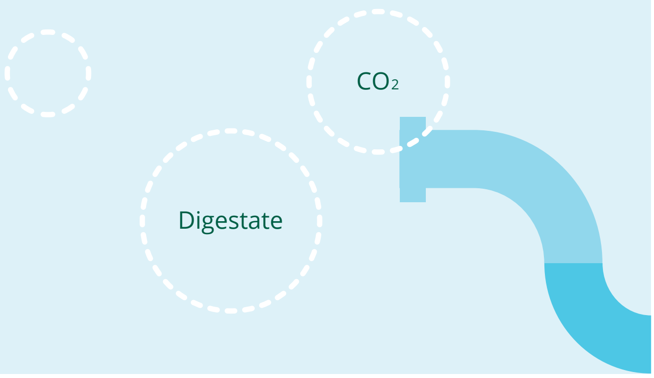
The term digestate is used because it describes the digested material that leaves the biogas plant after fermentation. It is rich in nutrients and is typically applied to agricultural fields. The digestate is usually used as fertilizer without further treatment. At many biogas plants it is separated into liquid and solid digestate and can then be applied to fields with conventional fertilizing equipment and optimized logistics. Several technologies exist, which allow further treatment of the digestate in order to produce products with extra value, such as a high concentration of nutrients as nitrogen and phosphorous products on the one hand and clean water that can be added to natural rivers or used for irrigation on the other.

CO2

During the biogas upgrading process CO2 is removed from the biogas. The purity of the CO2 differs between the different upgrading technologies. CO2 can be relevant and valuable for a number of industrial processes – for example the food, cooling or natural gas extraction (backfilling) industry as well as for other applications, which require sustainable carbon. Further uses may gain in importance in the future, such as for power-to-gas applications. H2 can be produced by electrolysis and in a further step be combined with CO2 to produce renewable methane. Depending on the storage and use possibilities of the gases this can be a beneficial model.

Chemical Feedstock

Biomethane can substitute natural gas in the chemical industry, such as intermediates for platform chemicals, syngas or methanol. This applies for many applications and is another path for decarbonization.



3

Why incentivize biomethane production and use?

Biomethane has many economic and ecological advantages. Not only is it a perfect example of a circular economy, but it also strengthens local and regional economical networks by providing local value chains. Biomethane is flexible and versatile; it can be generated out of a wide range of organic materials and easily stored over long periods of time. Unlike most other renewables, the production of biomethane through biogas is suitable for base loads or even flexible energy supply since it can be planned and controlled, especially by storing the biomethane in the gas grid or gas storage.

Biomethane is not only made from organic wastes, but typically part of a needed disposal solution. For example, biomethane is produced from wastewater while the fermentation helps reduce the amount of sewage sludge. This applies to municipal as well as industrial wastewater, e.g. pulp and paper factories.

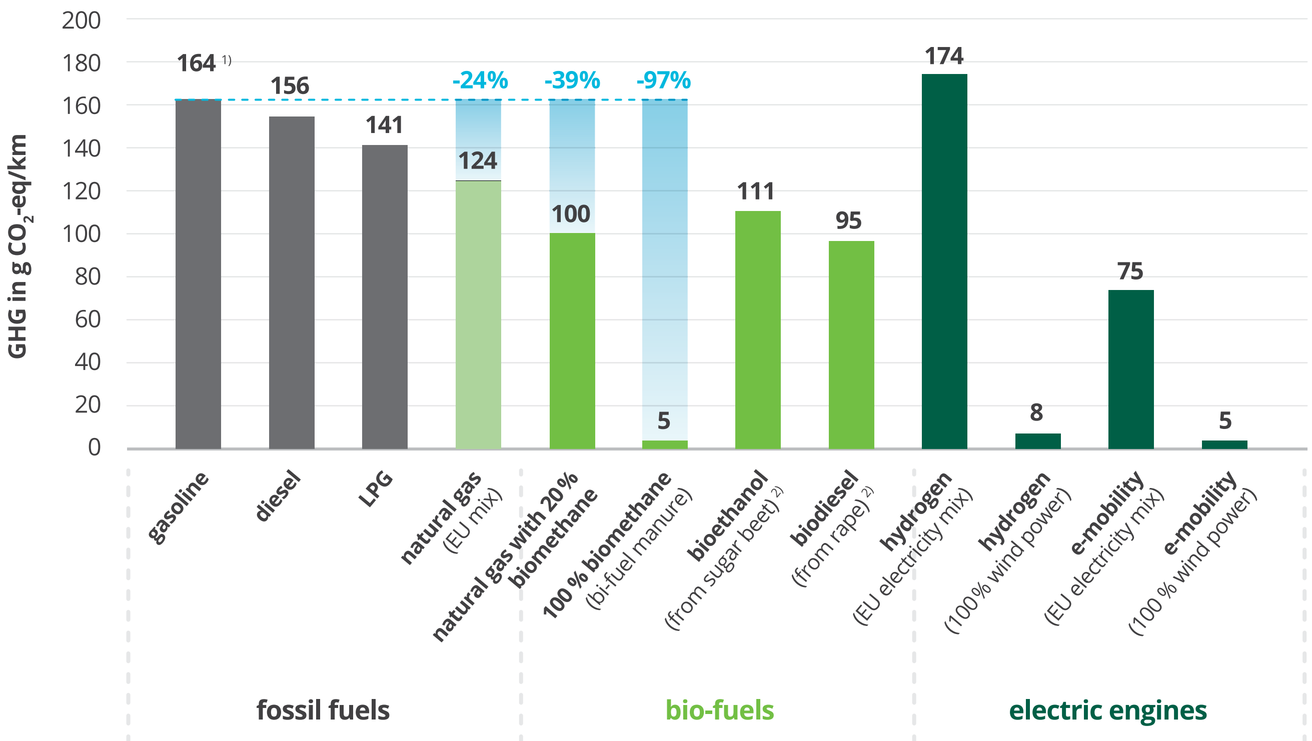
Infrastructure and equipment suitable for biomethane is readily available and finding knowledgeable personnel should be relatively easy, especially compared to other new energy fields. Due to the interchangeability with natural gas, it is often easy to have a backup gas grid connection.

Biomethane is deemed as one of the most carbon-saving fuels for transportation or heating. In addition, up to 90% of particulate matter, up to 80% of nitrogen oxide (NO_x) and up to 50% of noise emissions can be cut in comparison to using diesel or gasoline as a vehicle fuel. The NOx and particulate matter emission reduction also applies for substitution in processes such as oil or coal-fired heat boilers or power supply plants. Moreover, sulphide oxide (SO_2) emissions are cut down close to zero. Thus, the use of biogas and biomethane contributes significantly to local air quality improvement.

Another aspect, which is important for the use of biomethane as a vehicle fuel, is the potential distance travelled. CNG vehicles typically offer a travelling range close to or comparable with conventional fuels.

However, biomethane production costs are higher than those of fossil fuels. Hence, in order to realise ambitious climate action plans, politicians need to help set up the right framework conditions for creating business cases for biomethane producers. As long as GHG reduction does not have a positive business case on its own, incentives will be required to speed up the substitution of fossil fuels by biomethane.

Figure 2: Greenhouse gas reduction comparison.



1) Reference: gasoline engine with 7.1 l/100km; 2) Residues used as animal feed

Source: (IRENA, 2018)

Spotlight 2

Typical business cases for biomethane production and use in Germany

Different business cases for biomethane production in Germany exist, depending on the path chosen for marketing biomethane. The following examples show typical cases and their underlying considerations.

Biomethane for CHP

In many cases, biomethane is taken from the gas grid and directly used in CHP units for the co-generation of electricity and heat. The CHP units are operated only when there is a local heat demand and the heat is sold at a price, which is competitive with alternative heat supply options (e.g. natural gas or wood chip boiler).

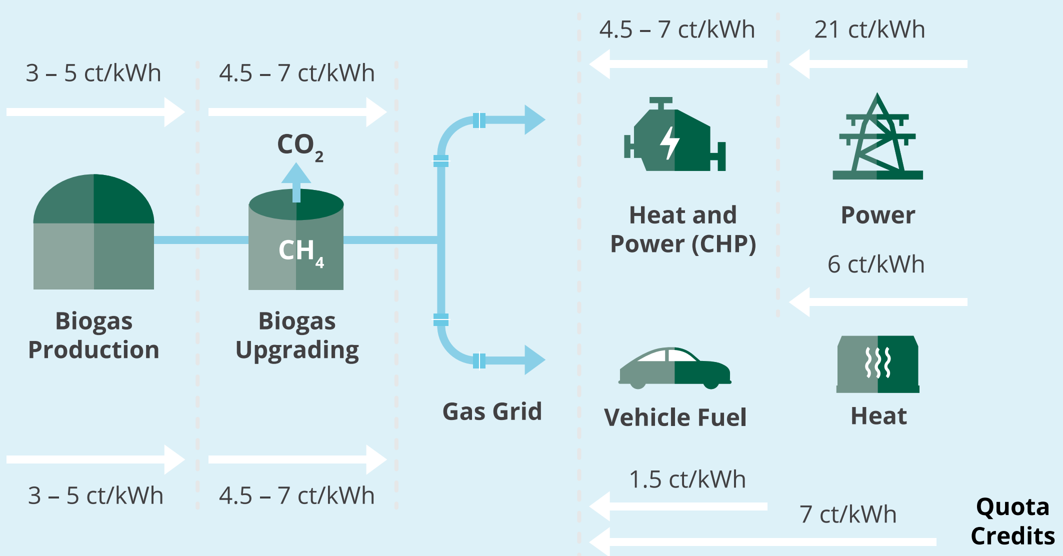
The electricity produced is typically fed into the electricity grid and feed-in-tariffs for green electricity are collected from the electricity grid operator. The CHP unit is operated by the heat consumer or an energy supply company, which sells the heat based on a heat delivery contract.

Biomethane for heating

Since biomethane can be used interchangeably in any natural gas application, it can be used for central-heating boilers. In Germany around 200 gas companies offer gas heating products with mixtures ranging from 5 to 100% biomethane. Private and industrial customers connected to the gas grid can choose their gas supplier independently of the ownership of the local gas grid.

Biomethane as vehicle fuel

Biomethane as a vehicle fuel has been a niche market in the past, but is gaining in importance as more focus is placed on decarbonization of the transportation sector. The EU's Renewable Energy Directive II (RED II) creates a foundation for legislation and incentives for advanced, carbon-saving fuels from biomass. Biomethane from waste and manure has the highest CO2 reduction potential compared with biogas from energy crops and other renewable fuels due to avoided methane emissions, which would occur if the manure were not processed in the biogas plant.

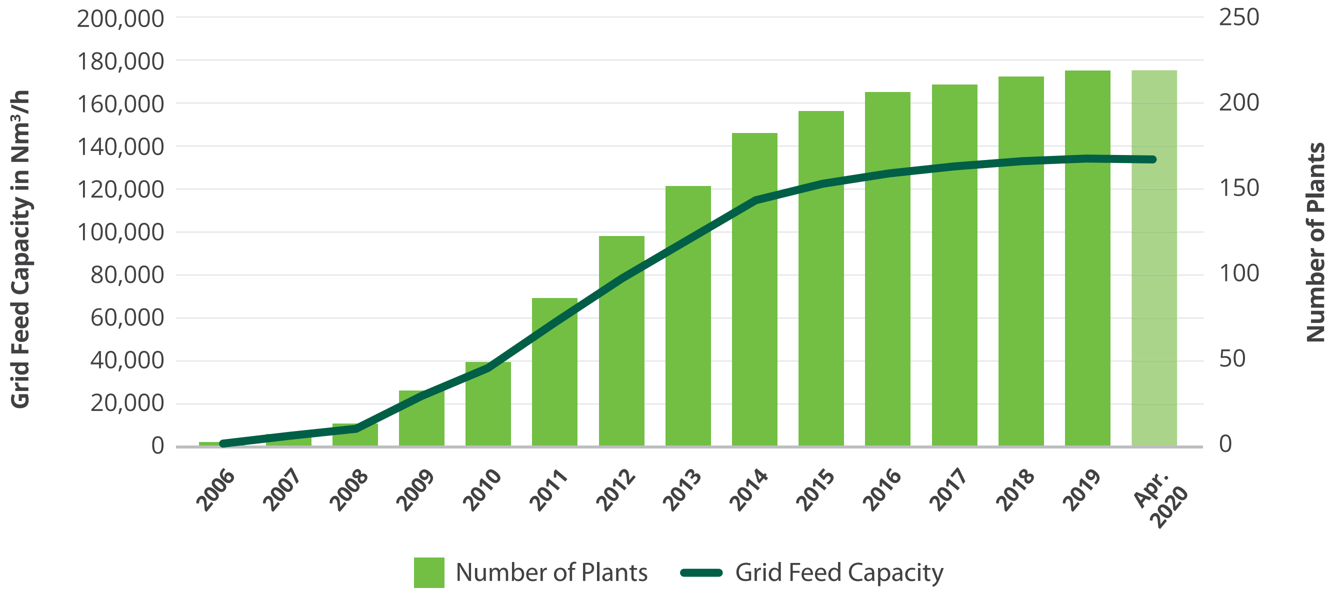


4

Biomethane production and use in Germany

The number of biogas upgrading plants increased rapidly between 2006 and 2014 as can be seen in Figure 2. Thereafter, the development was slowed by less favourable market conditions and incentives. The concrete incentives and measures, which influenced the growth are described in detail in Section 7. Nowadays, over 11 TWh of biomethane are produced in Germany annually.

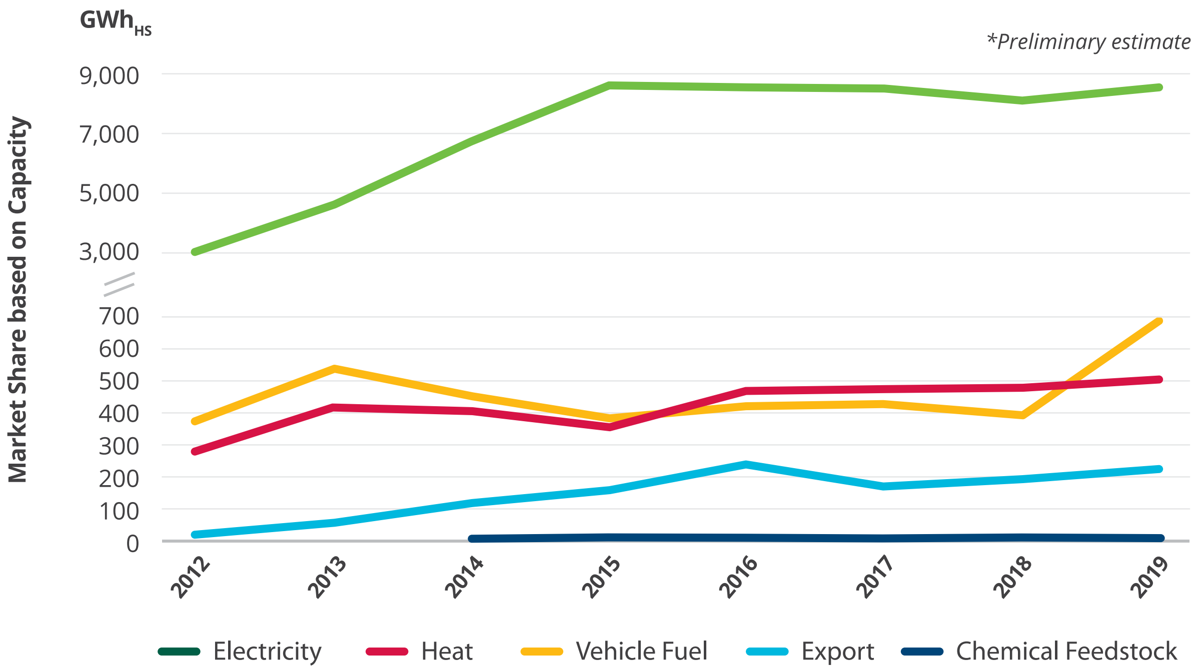
Figure 3: Number of biogas upgrading plants and their gas grid feed capacity development from 2006-April 2020



Source: (dena Deutsche Energie-Agentur, 2020)

There are several markets for biomethane in Germany, mainly as vehicle fuel, electricity and heat supply (for details see Figure 4). The main path for biomethane utilization is CHP cogeneration. Only about 5 % of all biomethane in Germany is used for gas boiler heat production and currently around 5 % for vehicle fuel use with a strong upward trend. This is mainly due to the fact that electricity production has been more strongly incentivised. Until recently, biomethane was not given preferential treatment over natural gas for heating purposes.

Figure 4: Markets for biomethane in Germany - yearly consumption levels from 2012 to 2019.



Source: (dena Deutsche Energie-Agentur, 2020)

In view of the current status of biogas production and use in Germany the actual focus of biogas producers is the transition from the existing support schemes focussing on electricity production towards new long-term business cases. It is expected that the number of new biogas plants will be limited and mainly focussed on small scale manure digestion plants for electricity production as well as medium scale plants utilising organic wastes to produce biomethane for the vehicle fuel sector.

For the biogas plants, for which the 20-year feed-in-tariff guarantee ends – which takes place for the first plants this year (2020) – the main question is how to reduce biogas production cost and address new customers for biogas, carbon dioxide as well as for valuable fertiliser to build up new value chains. There has been great interest in the realisation of the following strategies:

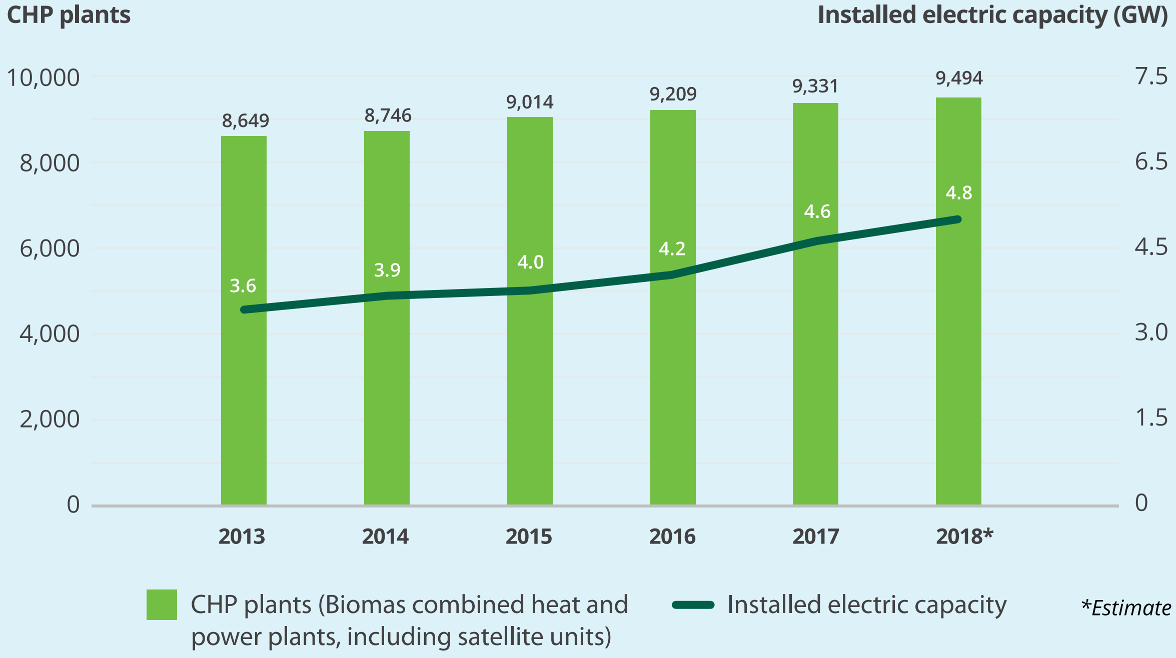
- switching from energy crops to manure, deep litter as well as residues as a substrate basis
- switching from feed-in-tariffs to supply of the plant's own electricity and heat demand on-site combined with flexible electricity supply for the electricity grid at times when wind and solar electricity are not available
- switching from electricity production to biogas upgrading for biomethane and gas grid injection or transition of the own vehicle fleet to use biomethane as vehicle fuel e.g. for own trucks and tractors.

Typically, a mixture of these options seems to be a strategy for continued biogas production and use. However, due to extreme low fossil energy prices and strong competition in renewable energy supply it is to be expected that some biogas plants will not survive on an economic basis in Germany. The general expectation of the biogas plant operators is that they find a solution for continued operation, although the amount of biogas and energy produced could be decreased. Regarding the question of the role of biomethane in Germany, it can be clearly expected that substitutes for the important energy source natural gas will be in increasing demand in the future. Biomethane is the only option which is available technically today at a reasonable price. Thus, the number of biogas upgrading plants in Germany is expected to grow significantly in the coming years, mainly based on the currently existing biogas production plants.

Spotlight 3

Biogas production for local heat and power production in Germany

In contrast with biomethane, biogas is mainly used for local electricity and heat production in Germany. To give a comparison, the following figure visualizes the status of combined heat and power units in Germany.



Source: FNR based on DBFZ Fachverband Biogas e.V. (2018)

20 years ago the German government realized that GHG mitigation in the energy sector would be highest by substitution of coal-based electricity production with renewable energy. Based on that fact strong incentives were introduced to stimulate renewable electricity production, among which was solar and wind power along with biogas. Due to this development, electricity production from biogas increased strongly until 2012 and still dominates biogas use in Germany today.

Spotlight 4

FAQ Biogas & Biomethane in Germany

Why is biomethane mainly produced from energy crops in Germany?

The development of energy crops in Germany is strongly tied to the agricultural policies of the European Union in the 2000's. Due to imports and a food production surplus at the time, the EU paid farmers to set aside some of their cultivated land, on which they were not allowed to grow food and feed crops. After the end of these payments the German government found an alternative to make utilization of this cultivated land attractive again. The Renewable Energies Sources Act (EEG) came into effect in 2004 with strong incentives for the cultivation of energy crops. The EEG provided a lucrative feed-in-tariff, which was guaranteed for 20 years and provided a good business case for investments into biogas plants. Therefore, many biogas plants were established based on energy crops as substrates.

Why is the biomethane plant capacity in Germany often the same?

Based on the economies of scale, the larger the biomethane plant, the lower the specific costs for upgrading. This is the reason that the EEG incentive scheme gives higher support for smaller units and in this way favors the construction of certain upgrading plant sizes – up to 700 m^3/h biomethane production capacity a 3 ct/kWhel bonus is offered, up to 1,000 m^3/h 2 ct/kWhel and up to 1,400 m^3/h 1 ct/kWhel, with no incentives past this point. Hence, most biomethane upgrading plants were built in the range between 350 and 1,000 m^3/h biomethane production capacity.

Why is biomethane in Germany mainly being used in CHP units?

Due to the existing EEG incentives, electricity generation is the most lucrative business case for biomethane utilization in Germany. Business cases are even more profitable in the case of CHP cogeneration with heat customers in proximity. However, the decreasing production cost for electricity from solar and wind has made the economic viability of this model questionable. The biomethane market is expected to change in the coming years. Recently, German policymakers have enacted new indirect incentives (e.g. carbon tax on fossil energy and incentives for GHG reduction from the vehicle fuels sector), which will most likely spur the development of biomethane in the transportation and heating sector.

5

Case studies

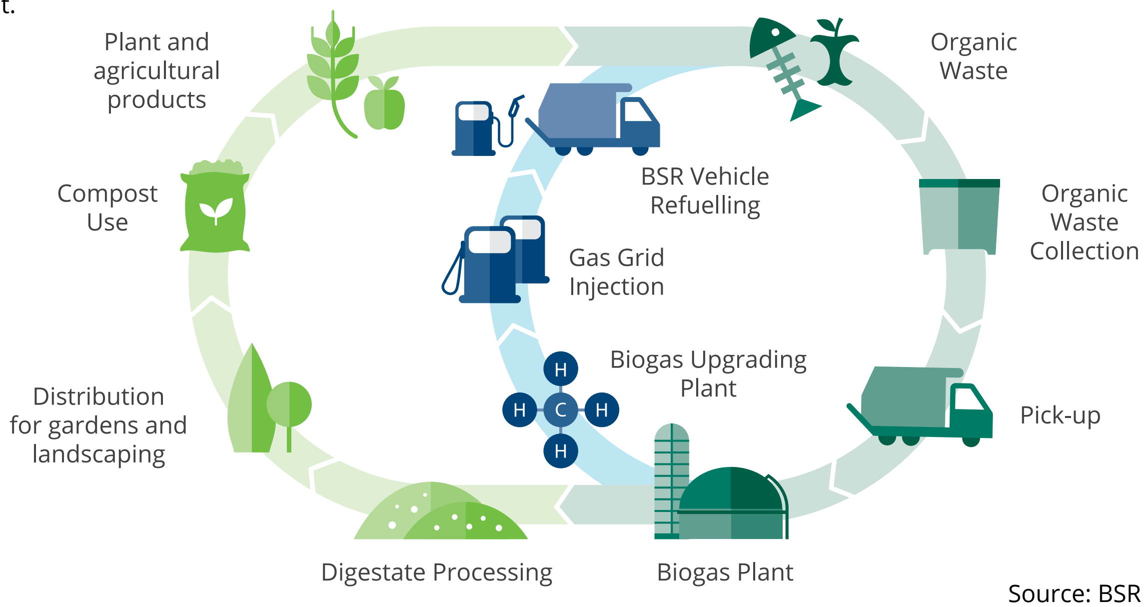
In this chapter three different case studies are presented, which demonstrate three different models for biomethane production and use. The first plant is operated by a municipal waste disposal company, the second by a farmers' cooperative and the third by a municipal wastewater authority. The waste plants – both for municipal household waste and wastewater – typically receive gate fees for the waste they treat and are not solely dependent on the income from the gas production.

5.1 The Municipal Waste Authority in Berlin (Berliner Stadtreinigung BSR)

The municipal waste authority in Berlin was one of the early adopters of the bio bin system and has been collecting municipal organic waste for nearly 20 years. The company uses the biomethane produced from part of the city's organic waste to fuel 150 of the city's waste collection vehicles. The digestate is used as fertilizer in several applications. The visibility of the biomethane vehicles raises awareness for the advantages of utilising the energy potential of organic waste.

Figure 5:
View of the BSR facility with biogas upgrading plant in the upper-left corner.

Figure 6:
The closed cycle of the BSR biogas plant.



Source: BSR

Table 1:
Key figures from the BSR plant

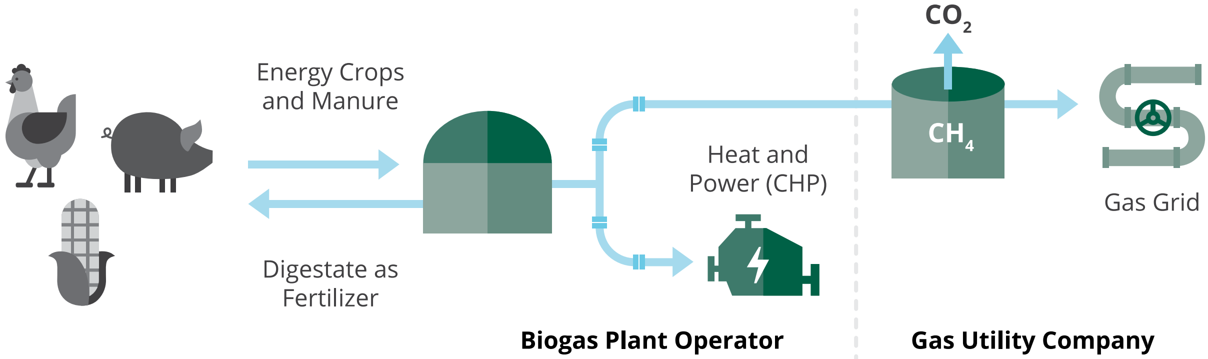
Date of operation begin	2012
Feed-in capacity	3,600,000 m³/a
Gas upgrading technology	Amine Scrubber
Input substrates: Municipal organic waste	60,000 t/a
Solid digestate	19,000 t/a
Liquid digestate	30,000 t/a

Source: BSR

5.2 GraNott GmbH – Biogas Plant Grabsleben

The ownership at the biogas and biomethane plant in Grabsleben is split between the farmers, who own and operate the biogas plant and CHP unit, and the regional gas utility company, who owns and operates the (biogas to biomethane) upgrading plant (see **Figure 7**).

Figure 7:
Division of ownership and operation responsibility at the biogas plant and biogas upgrading plant in Grabsleben



The substrates for the biogas plant in Grabsleben are derived from the farmers' cooperative's own products as well as chicken manure from a local farmer and other external sources. The biogas produced is for about 50 % used for local electricity production with electricity grid feed in and for about 50 % for upgrading and gas grid injection. The plant purchases its electricity demand for operation from the free market and receives the feed-in tariff for the electricity it produces. It is typical that a biogas plant sells all the produced electrical energy for a higher price and then it buys the electricity from the grid although it is always a net producer. Some heat from the CHP unit (around 30-50 % depending on the season) is not sold, but rather used on-site for drying digestate, operating an ORC unit (which produces electricity out of heat) and providing the necessary heat for operation of the amine scrubber for biogas upgrading. The produced biogas is sold to a local gas utility company, which operates the upgrading plant located at the biogas plant – the point of transfer being on site. The gas is then injected into the natural gas grid and sold all over Germany.

Figure 8:
CHP unit (left), ORC unit (right) and biogas upgrading plant (middle/upper right) at the biogas plant in Grabsleben

Table 2:
Key figures from the biogas plant Grabsleben

Date of operation begin	2010
Feed-in capacity	Approx. 6,000,000 m^3/a (only part of the gas is upgraded)
Gas upgrading technology	Amine scrubber
Input substrates:	
Energy crops	45,000 t/a
Pig manure	40,000 t/a
Chicken (and cow) manure	20,000 t/a
Digestate fertilizer	Approx. 95,000 t/a

5.3 Wastewater treatment plant Hamburg

The wastewater treatment plant in Hamburg is the largest wastewater treatment plant in Germany with respect to the input. In order to boost biogas production, co-substrates, such as cafeteria waste and glycerine from biodiesel production, are added to the sewage sludge. The biomethane is marketed to Hamburg's residents as a biomethane/natural gas mixture. The sewage sludge is not directly used as fertilizer, but incinerated at a mono-incineration plant today. The mono-incineration increases the concentration of nutrients in the ashes and allows re-use in agriculture when nutrients, especially phosphorous is separated. However, technologies for nutrient recycling are under continuous development and need advancements before it is lucrative. Due to governmental requirements phosphorous recycling is obligatory for treatment plants for more than 100,000 inhabitants and the respective technologies are in the piloting phase today.

Figure 9: Birds-eye view of the Hamburg Wasser facilities with fermenters in the background

Source: Hamburg Wasser

Table 3: Key figures from the wastewater treatment plant of Hamburg Wasser

Date of operation begin	2011
Feed-in capacity	Approx. 2,500,000 m^3/a
Gas upgrading technology	Amine scrubber
Input substrates: Wastewater and Co.-substrate (cafeteria waste and glycerin from biodiesel production)	158,700,000 m^3/a
Incinerated sewage sludge	35,400 t dry mass/a

Source: (Hamburg Wasser, 2020), (Hamburg Wasserwerk GmbH, 2019)

5.4 Sino-German Strategic Alliance for Advanced Biomethane Technology

In the "Sino-German Strategic Alliance for Advanced Biomethane Technology" public and private partners build up a replicable flagship biomethane demonstration project based on Best Available Techniques and Best Environmental Practices in Inner Mongolia. The project is jointly developed by Deutsche Gesellschaft für International Zusammenarbeit (GIZ), GICON Großmann Ingenieur Consult GmbH, Evonik Specialty Chemicals (Shanghai) Co., Ltd. and Binder Engineering GmbH. Funding for the project comes from the involved German companies, the Ministry of Agriculture and Rural Affaires (MoARA) and the German Ministry for Economic Cooperation and Development (BMZ) in the context of the develoPPP.de programme.

The project period is from 06.2018 to 05.2022 with total investment of 70 million CNY (8.7 million EUR), which includes 20 million CNY (2.5 million EUR) of the construction subsidy from the Ministry of Agriculture and Rural Affaires (MoARA). The demonstration plant is located in the modern agricultural and husbandry park in Keyouqian county, Ulanhot city in Inner Mongolia owned by Inner Mongolia Hope Mengneng Energy & Environmental Technology Company. Using the overall design provided by GICON, three anaerobic fermentation tanks will be built with a diameter of 18.5 metres and a height of 18.5 metres. Crop straw and pig manure will be mixed and sent to the CSTR anaerobic fermentation unit. The biogas produced will be upgraded to biomethane by a three-stage membrane purification from Evonik and fed into a gas pipeline. After the solid-liquid separation of the residue, the solid part will be treated with aerobic decomposition and used as organic fertilizer. The liquid part will be processed to liquid organic fertilizer and used for organic rice and vegetable farms.

Date of operation begin	**Planned in 2021**
Feed-in capacity	Approx. 3,600,000 m^3/a
Gas upgrading technology	Membrane
Input substrates: Energy crops Pig manure	 13,500 t/a 146,000 t/a
Digestate fertilizer	Approx. 50,000 t/a

Figure 10:
View of the modern agricultural and husbandry part

Source: Hope Mengneng company.

In cooperation with MoARA, the project will build up a national-wide modern system to monitor the performance of biogas plants in China online. The demonstration plant will be the first plant to be connected to the system and to transfer real-time data, which plays an important role for developing a new output-based subsidy scheme. The equipment will be provided by Binder. Meanwhile, policy recommendations gathered from the Sino-German cooperation plant will be given to MoARA to further promote the development of the biomethane sector in China. Till now, suggestions from the project have been successfully adopted during the making of the "technical specifications for scaled biogenic natural gas engineering" and the "technical specifications of remote monitoring for biogas engineering" (both are industry standards of MoARA). Based on the findings from the demonstration plant, a new standard regarding environment and safety is under preparation. The project also provides opportunities for the German and Chinese biogas industry to participate in the Sino-German Strategic Alliance and to exchange on technologies as well as standards between the two countries.

For further information on the project, please contact Ms. HOU Jingyue of GIZ (jingyue.hou@giz.de).

Partners of the Sino-German Strategic Alliance for Advanced Biomethane Technology

Binder Group AG

Technologies:	COMBIMASS® Gas analysis and gas flow measurement systems		
Standard Capacities:	0.08Nm/s~400Nm/s		
Units in operation:	> 5,500 pcs	Tel:	+86 13817172998
Units in China:	> 220 pcs	Mail:	gavin.liu@binder-instrumentation.cn
Contact for request from China:	Mr. Gavin Liu	Website:	www.bindergroup.info

GICON Großmann Ingenieur Consult GmbH

Technologies:	Wet anaerobic digestion & two-stage solid-liquid anaerobic digestion process (GICON Process)		
Treating Capacities:	Depending on feedstock amount, 10-100t/d DM equivalent.		
Reference projects:	180+	Tel:	+86 755 8253 0401
Reference in China:	2	Mail:	max.ren@gicon-aet.com
Contacts for requests from China:	Mr. Max Ren	Website:	www.gicon.de/en
Link to references:	www.gicon.de/en/geschaeftsbereiche.html		

Evonik Fibres GmbH

Technologies:	SEPURAN® Green Membran Technologie
Standard capacities:	15 – 5,000 Nm^3/h raw biogas
Units in operation:	> 350
Units in China:	> 35
Contacts for requests from China:	Mr. Bruce Wu
Tel:	+86 136 5185 7662
Mail:	bruce.wu@evonik.com
Website:	www.sepuran-green.com
Link to references:	www.sepuran.com/product/sepuran/en/biogas-upgrading-membranes/references/

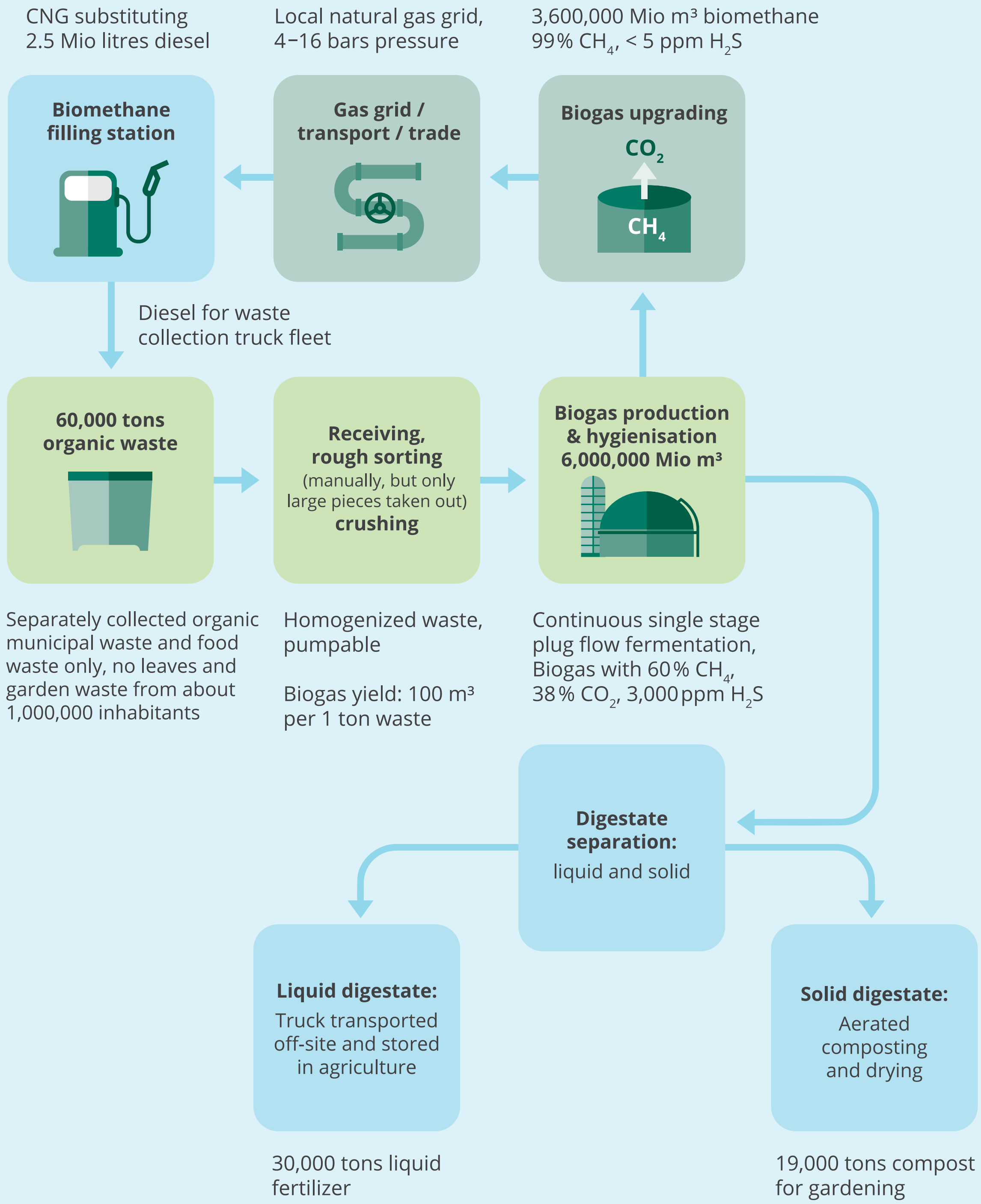
6

Technologies for biomethane production and natural gas grid injection

Spotlight 5

Organic waste recycling in the city of Berlin

Total: 9,000 tons CO_2 emission reduction and sustainable nutrient as well as energy circulation



6.1 Biogas supply and cleaning

Biogas cleaning and upgrading are two separate – although sometimes overlapping – processes. Biogas cleaning refers to the process, which is necessary even for biogas combustion in a CHP unit. In this process, potentially harmful impurities are separated from biogas. The "cleaned" gas is still a CH_4 and CO_2 mixture. Biogas upgrading, on the other hand, refers to the separation of CH_4 and CO_2 to produce "pure" biomethane – a prerequisite for biomethane grid injection in Germany.

6.1.1 Desulphurisation

One of the most important steps in biogas cleaning is the removal of sulphur. Desulphurisation is necessary in order to avoid problems, such as corrosion and SO_2-emissions. In addition, other trace gases and impurities need to be removed from the biogas. Hydrogen sulphide (H_2S), for example, can cause corrosion in carbon steel components in gas pipelines. For this reason, the limits for H2S for grid injection are very low (see Table 8).

There are biological, chemical and physical options for desulphurisation of biogas, typically a combination of different technologies is applied to achieve the standards required for the gas grid.

Biological desulphurisation can be in the form of air (oxygen) injection into the gas dome of a digester, an external biological reactor with a trickling filter process, or biochemical gas scrubbing. To avoid high nitrogen concentrations in the biogas, which cannot be easily removed at many plants, purified oxygen is commonly used for desulphurisation.

Chemical desulphurisation can be carried out by adding iron hydroxide and/or iron salts to the fermenter. This method is simple and effective but is associated with higher operational costs.

For grid injection, activated carbon filter technology is always applied as a last step of desulphurisation. Typically, activated carbon filters are the only technology to safely achieve H2S concentrations below 5 ppm in the gas.

Table 4: Overview of the advantages and disadvantages of desulphurization technologies

Technology	Advantages	Disadvantages
Internal biological -desulphurization	Cheap & simple pre-desulphurisation for further gas treatment No additional equipment except a small compressor Sufficient for cogeneration	Little control Air (nitrogen) reduces heating value
External biological -desulphurization	99% cleaning at high load Without chemical products Less corrosion in fermenters	High amount of air necessary (depending on technology used) Air (nitrogen) reduces heating value Maintenance of filters Investment cost
Biological scrubber	95% cleaning No oxygen close to fermentation process	Nutrients addition necessary Investment cost
Sulphide precipitation in fermentation	Simple process with addition of iron salts or iron hydroxide into fermentation Good removal rate Oxygen does not influence biogas process (no reduction of heating value)	High additive costs Difficult dimensioning Costs for security measures
Activated carbon filter	Fine desulphurization (gas grid injection and use as vehicle fuel) with concentrations far below 5 ppm safely achievable	Cost of filter regeneration

Adapted from: (FNR Fachagentur Nachwachsende Rohstoffe, 2014)

6.1.2 Drying

Drying is a necessary step of the gas cleaning process, because it helps protect downstream equipment and aggregates (compressor, motor) from corrosion. When biogas leaves the digester, it is fully saturated with water vapour at a high temperature. One of the main methods of drying the biogas is through cooling. Some biogas upgrading technologies require the biogas to be free of condensing water vapour to guarantee long life performance.

Cooling is often carried out by gas pipes in the ground and corresponding collection of condensation in a stripper. Furthermore, this process makes it possible to remove other unwanted impurities, such as water-soluble gases and aerosols. For biomethane upgrading and injection into the gas grid this must be combined with electrical cooling. Depending on the upgrading technology used (see 6.2), cooling and drying may be considered separate steps and drying may take place prior to or after upgrading (CO_2 removal).

6.1.3 Removal of other impurities

Volatile organic components (VOC), ammonia and siloxane can also appear as trace gases, depending on the substrate's composition. To protect the biogas upgrading equipment, measures such as special activated carbon filters must be used to reduce these components.

6.2 Biogas upgrading

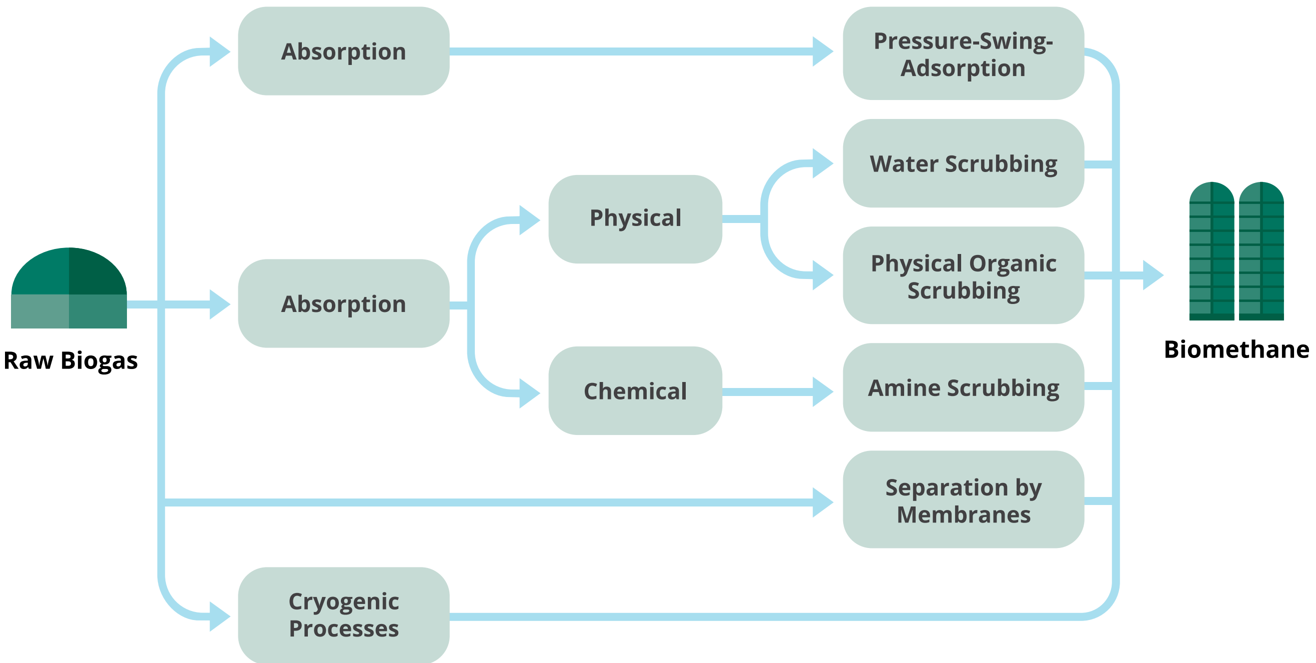
A substantial share of raw biogas is CO_2 – typically ranging from 35 to 45% depending on the source or feedstocks (Korres, et al., 2013). CO_2 requires removal in order to optimise the energy content of the gas. For gas grid injection, the requirements for the purity level of biomethane (i.e., CH_4 content) are relatively high to achieve a gas quality identical to that of natural gas – especially with regard to the combustion characteristics (e.g., heating value etc.).

There are different technologies to remove the CO_2 content. One method for separation is based on the adsorption behaviour of CH_4 and CO_2 at different pressure levels. Other technologies are based on the principle of solubility of the gases, i.e., by using a solvent – such as water, amines or organic solvents – which has a high solubility for CO_2 and allows CH_4 to pass through unaltered. Yet another possibility is separation based on membrane filtration based on the molecular sizes of the two gases.

Some of these technologies produce an offgas with pure or very high CO_2 concentration. Solutions for further use and marketing of this valuable side stream are under practical test and development and should be considered for full integration of a biomethane plant e.g. in biorefinery or Power-to-Gas concepts.

An overview of the technologies based on their separation principle can be found in Figure 11. The most common are either pressure swing adsorption (PSA), physical absorption through water scrubbing, membranes and chemical absorption through amine scrubbing. The number of upgrading plants with the different technologies, which are in operation in Germany and around the world from 2019 are shown in Figure 12.

Figure 11: Overview of general options for biogas upgrading / CO_2 removal from biogas



Pressure swing adsorption is relatively wide-spread and has a long history. It functions basically on the principle that CO_2 adsorption on specialised molecular sieves is different for certain materials at different pressures. The pressure is increased and the gas flows through a molecular sieve. The CO_2 is retained in the sieve and separated from the CH_4. Afterwards, the pressure is reduced, the CO_2 released and the sieve regenerated. This technology delivers biomethane at high pressure of typically about 10 bar, which is advantageous for direct gas grid injection.

Selected companies in Germany's biomethane sector

Alba China Recycling Solutions Ltd.

Technologies: Water Scrubbing, Membrane

Standard Capacities: 1,250 Nm^3/h raw biogas for water scrubbing, 1,000 Nm^3/h raw biogas for membrane

Units in China: 2 (1 in construction)

Contact for request from China: Yunfei Zhan

Mail: yunfei.zhang@albagroup.asia

Tel: 13436506319

Website: www.alba.info

Biogasaufbereitung Süd GmbH

Technologies: Membranes, Pressure Swing Adsorption

Standard Capacities: 150 – 2,000 Nm^3/h raw biogas

Units in operation: > 25

Units in China: 2

Contact for request from China: Mr. Xi-Lou

Tel: +86-13521764619

Mail: xi.lou@biogasaufbereitung.de

Website: www.biogasaufbereitung.de

Link to references: www.beispielanlagenliste.de

BMF HAASE GmbH

Technologies: Organic-Physical Absorption with polyglycols - scrubber driven by electric power

Standard Capacities: 500 – 5,500 Nm^3/h raw biogas

Units in operation: 20

Units in China: 0

Contact for request from China: Tim Steinbrecher, CEO

Tel: +49-878-110

Mail: tim.steinbrecher@bmf-haase.de

Website: www.bmf-haase.de

Carbotech Gas Systems GmbH – Germany

(100% shareholded Powerchina Group company)

Technologies: Membranes, Pressure Swing Adsorption, Scrubber

Standard Capacities: 100 – 4,000 Nm^3/h raw biogas

Units in operation: >90

Units in China: 1 under construction

Contact for request from China: Dr. Alfons Schulte

Tel: +49 201 50709-303

Mail: alfons.schulte@carbotech.info

Website: www.carbotech.info

Link to references: www.carbotech.info

ETW Energietechnik GmbH

Technologies:	ETW SmartCycle® Pressure Swing Adsorption technology
Standard Capacities:	300 – 5,000 Nm^3/h raw biogas
Units in operation:	> 10
Units in China:	0
Contact for request from China:	Mr. Oliver Jende
Link to references:	http://etw-energie.de/produkte/biomethan-anlagen/

Tel: +49 28419990203
Mail: jende@etw-energie.de
Website: www.etw-energie.de

There are several absorption technologies, which are based on different principles - the first difference being physical and chemical absorption. Water scrubbing is a widely-used form of physical absorption. The process is based on the solubility and polarity of CH_4 (non-polar) in water as opposed to CO_2 and H_2S (polar). The advantages of the system are that it does not require chemicals, simultaneously removes CO_2 and H_2S and does not require upstream drying. Only rough desulphurisation is required before upgrading. However, water is required and the potential for corrosion as well as microbial growth in the system are given. The biomethane leaves at high pressure of typically about 10 bar.

Physical absorption is based on organic solvents, such as the case for scrubbers. The process is generally based on the same principles as water scrubbing, such as solubility of the compounds in the chemicals. Less chemical solvent is required than water in water scrubbing and it is used in a generally closed system. Prior H_2S removal is highly recommended. The biomethane leaves at high pressure of typically about 10 bar.

Chemical Scrubbing is mainly based on amines with a very good and very selective solubility of CO_2. Residual H_2S is removed. The biomethane reaches the highest methane concentrations and the loss of methane in the offgas is lowest compared with the other typical technologies. But the technology needs chemicals for operation and requires a high heat input (mostly at 130 or 140°C) for amine recycling. This is an advantage to explore locations where large amounts of waste heat are available. The biomethane leaves at low pressure close to ambient conditions.

Hitachi Zosen Inova AG

Technologies:	Membranes, Amine-scrubbing
Standard Capacities:	150 – 2,000 Nm^3/h raw biogas
Units in operation:	> 50
Units in China:	0
Contact for request from China:	Benoît Boulinguiez

Mail: info@hz-inova.com
Website: www.hz-inova.com

DGE GmbH

Technologies:	Amine scrubber and physical scrubber systems
Standard Capacities:	50 – 3,000 Nm^3/h raw biogas
Units in operation:	> 50
Units in China:	0
Contact for request from China:	DGE-INFO@t-online.de

Mail: www.dge-wittenberg.com
Website: www.dge-wittenberg.de/english/default.html

German Bio Energy Technology (Beijing) Co., Ltd

Technologies:	Biological waste treatment for dry agriculture and municipal waste to energy; Energy means biogas utilization to biomethane; Three core technologies available: Water, amine or membrane-scrubbing technologies.
Standard Capacities:	Including MSW and agriculture solid waste treatment: 1. MSW biological MBT process: 300t/d throughput. Biogas: 6,700,000 Nm^3/a 2. Agriculture manure biological treatment 1000m3/d cow dung water, 60t/d straw. Biogas: 8,760,000 Nm^3/a
Units in operation:	9 units (4 units under construction)
Units in China:	14
Tel:	+86-10- 8532/ 3549 / 3548 +0 or ext. 118
Mail:	info@germanbiowaste.com
Website:	http://www.germanbiogas.com/index.php?lang=en
Link to references:	http://www.germanbiogas.com/reference/img.php?lang=en&class1=102

Membrane separation has become increasingly widespread during the last several years, first for small scale plants, but is now available for all plant sizes. The separation process is based on the fact that the gas molecules are separated based on their size – passing or not passing through the membrane. The units are compact and are very flexible regarding adaption to larger and smaller gas flow by adding or removing single membrane units. Gas purity and methane losses can be controlled by the number of membrane stages with an impact on energy demand for operation as well as investment cost. The biomethane leaves at high pressure of typically about 8 bar.

Cryogenic separation is a quite new technology on the market without a German supplier. The separation process is based on the condensation of the different gases at extremely low temperatures far below 0°C. This requires high energy consumption, but the products can be a very pure liquid CO_2 and – if cooled down further – liquid methane as LNG from biogas. The technologies are quite sensitive to impurities in the gas, but further development is going on.

EnviTec Biogas AG

Technologies:	Membranes
Standard Capacities:	200 – 2,500 Nm^3/h raw biogas
Units in operation:	> 40
Units in China:	4
Contact for request from China:	Mr. Liu Xiao Lin
Link to references:	www.envitec-biogas.com

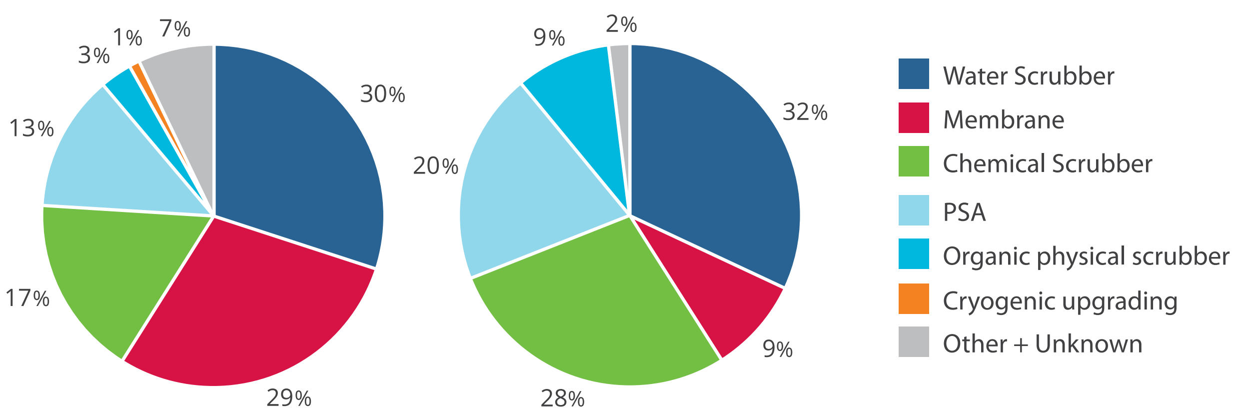
Tel:	+ 86 139 103 454 09
Mail:	liu.xiaolin@envitec.cn
Website:	www.envitec-biogas.com

agriKomp GmbH

Technologies:	Membranes
Standard Capacities:	150 – 2,000 Nm^3/h raw biogas
Units in operation:	> 3 (15 in construction)
Units in China:	0 (1 biogas plant with CHP)
Contact for request from China:	Mr. Chris Long
Link to references:	https://agrikomp.com/de/home-ak-de/anlagen/biogasaufbereitung https://agrikomp.com/home-int/biogas-plants

Tel: +44 7769 168586
Mail: chris.long@agrikomp.co.uk
Website: www.agrikomp.com

Figure 12: Market shares of the biogas upgrading technologies according to number of plants in operation world-wide (left) and in Germany (right).



Data source: (IEA Task 37, 2020)

Table 5: General parameters for biogas upgrading with different upgrading systems from selected suppliers (no general numbers concerning the different technical principles).

Process	**Upgrading Capacity** [m_n3/h Raw Biogas]	**Thermal Energy Demand** [kWh_{th}/m_n3 Raw Biogas]	**Electrical Energy Demand** [kWh_{el}/m_n3 Raw Biogas]	**CH_4 Loss** [%]
Amine Scrubber	250 – 2000	0.60	0.09	<0.1
Water Scrubber	250 – 2000	0	0.20 – 0.23	1
Pressure Swing Adsorber (PSA)	250 – 3000	0	0.14 – 0.20	1-1.5
Membrane	40 – 2800	0	0.12 – 0.35	0.5
Polyglycol Scrubber	110 – 2600	0	0.19 – 0.28	0.5-2

Source: (BMEL Bundesministerium für Ernährung und Landwirtschaft, 2019) and (Energiforsk, 2016)

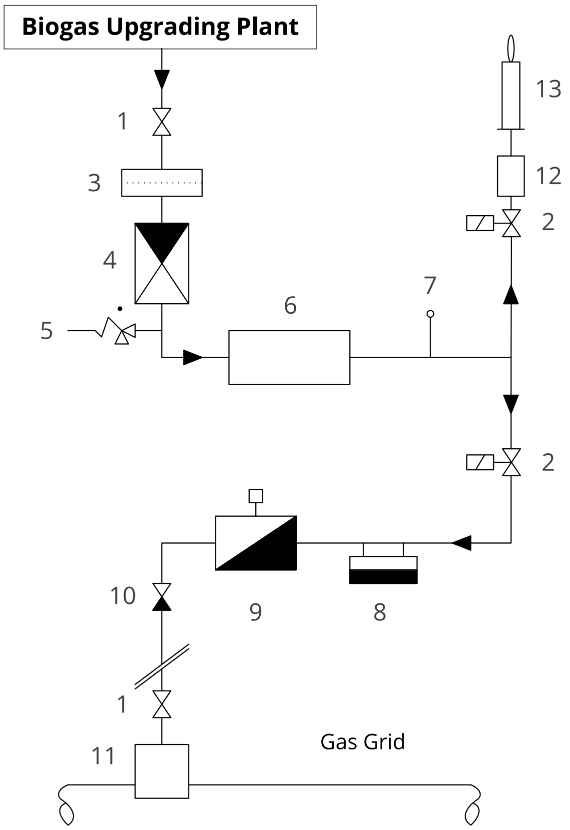
Table 6: Advantages for biogas upgrading with different upgrading systems and connected challenges

Process	Advantages – depending on the local conditions
Amine Scrubber	- Highest methane purity > 99 % possible - Lowest known methane losses in offgas (<0.1 % of input methane) - Lowest electricity consumption, but heat supply necessary locally - Gas output at ambient air pressure – only advantageous when low pressure application is given - Low ambient air temperature dependency of performance - Load between 50 % and 100 % tolerable
Water Scrubber	- No chemicals necessary, but biological clogging of columns possible - Tolerance against H2S load and water vapour in the biogas - Gas output at pressure above 8 bar – only advantageous when high pressure application is given - Load between 50 % and 100 % tolerable
Pressure Swing Adsorber (PSA)	- Dry process with low water vapour load in clean gas - No liquid chemicals necessary - Gas output at pressure above 8 bar – only advantageous when high pressure application is given
Membrane	- No chemicals necessary - Gas output at pressure above 8 bar – only advantageous when high pressure application is given - Load between 50 % and 100 % tolerable - Very flexible in up and downsizing - With additional membrane stages (typical is 2) high gas purity possible
Polyglycol Scrubber	- No biological clogging of columns - Tolerance against H2S load in the biogas - Gas output at pressure above 8 bar – only advantageous when high pressure application is given - Load between 50 % and 100 % tolerable

6.3 Gas grid injection

The gas grid injection unit is the interface between biomethane production and the gas grid which supplies customers with energy. Figure 13 shows the structure of a gas grid injection unit.

Figure 13: Scheme of a gas grid injection unit (conditioning could be necessary additionally and would be included after no.6)



1 Blocking valve
2 Automatic blocking valve
3 Filter
4 Gas pressure control
5 Security valve
6 Facility for measuring of gas quality
7 Temperature sensing device
8 Odorisation unit
9 Gas meter with electrical quantity transformer
10 Back pressure valve
11 Facility for mixing of the gas and regulation of flow rate
12 Armatures for flair
13 Flare

Source: Gasnetze der Zukunft (Urban (Hrsg.), 2010)

When biogas is injected into the gas grid the gas grid operator must guarantee a specific quality of the gas to the customers. The criteria for gas quality in Germany are provided in chapter 11. This is possible by:

- ensuring conformity of the injected gas with the conditions in the gas grid so that the gas quality in the gas grid is not significantly affected, or
- ensuring gas quality measurement of the mixture of the gas in the gas grid and the biomethane which is fed into the gas grid to be able to consider the resulting gas quality during accounting with the gas customers.

Gas quality is mainly influenced by the choice of upgrading technology and its operational parameters. In the case that the heating value in the gas grid is higher than a gas with 99 % methane, conditioning with LPG (liquified petroleum gas, containing mainly propane and butane) must be carried out. This is the case in some regions in Germany due to high propane concentrations in the natural gas. Moreover, there are regions with natural gas with low heating value, where dosing of air into the biomethane to reduce the gas quality takes place. Though all gas applications have security obligations, odorization of any gas entering the gas grid is required. A strongly smelling gas (e.g. thiolether or thiole) is added to the biomethane before it enters the gas grid.

The gas grid is always operated at a designated pressure range, in Germany low pressurised grids are operated at 400 mbar, transport gas pipes are operated in the range between 4 and 85 bar pressure. Depending on the biogas upgrading technology used the pressure of the biomethane at the outlet is between 100 mbar and 12 bar pressure, therefore, in many cases a gas compression is required to fulfil the necessary gas grid standard.

Last but not least, process control by process monitoring and control technology for quality and quantity measurement, control and regulation of all parts of injection unit and the thresholds of the gas standards must be installed. Safety-related control with automatic and mechanical safety equipment including protection of upstream and downstream equipment with respect to pressure, temperature and gas quality is installed at all gas grid injection facilities in Germany.

In case that the gas grid is not accessible for the biomethane (maintenance or defects) a flare must be connected so that the methane is oxidised to harmless CO_2 and not released as a gas with a strong GHG effect.

7

German framework for biomethane and standards

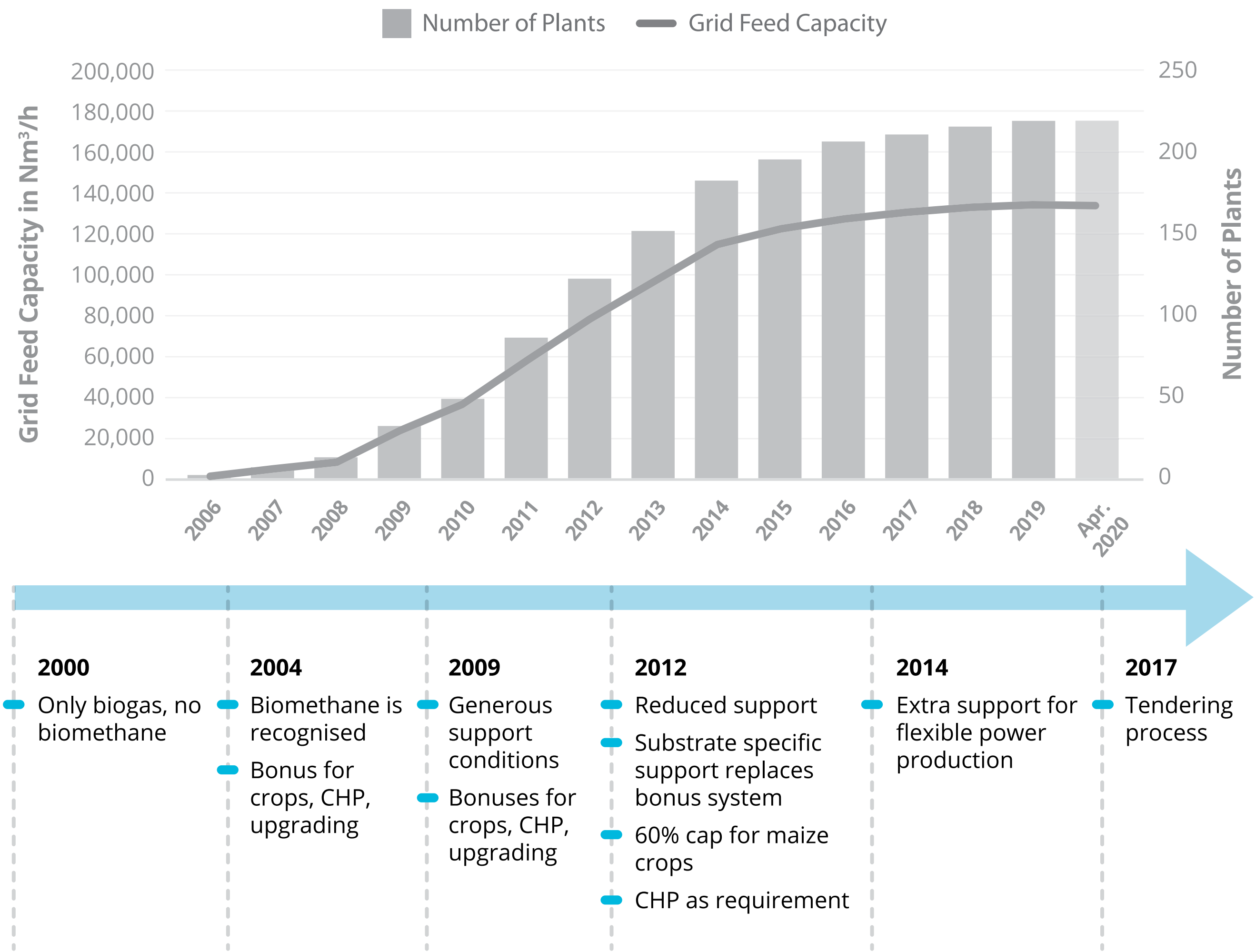
The following section takes a detailed look at the framework conditions for different applications of biomethane, e.g. laws and regulations to support and incentivise electricity or heat generation from biomethane. This includes a qualitative evaluation of the effects of Germany's policy framework and its influence on the biomethane industry.

7.1 Biomethane production

Germany is at present the country with the largest biomethane production/injection in Europe. About 200 plants inject biomethane into the German gas grid. Most of them have been built to produce biomethane for conversion into electric power. The production of electric power from biomethane is supported by the Renewable Energies Sources Act (EEG).

Figure 14 shows the development of Germany's biomethane industry along with relevant policy developments.

Figure 14: Market incentives for biomethane and their effect on the number of biogas upgrading plants and their gas grid feed capacity development from 2006-April 2020.



Source: (dena Deutsche Energie-Agentur, 2020)

Unlike other countries, German support schemes include neither a direct gas-grid feed-in tariff for biomethane nor direct funding of the biomethane production itself. Instead, there are several indirect support schemes or obligations focused on increasing the share of renewable energies (including biomethane) in electricity generation, heating and mobility. The most important incentive schemes or obligations supporting the development of biomethane cover:

- power generation from biomethane in CHP units
- biomethane as a vehicle fuel for natural gas vehicles
- heating and cooling of buildings

Figure4 shows that the most lucrative market for biomethane has been generating electricity for several years. Other important markets are heating and transportation (vehicle fuel). The support options for these different applications will be described in more detail in subsections 7.4-7.6.

7.2 Biomethane injection into the natural gas grid

Biomethane injection or transport in the gas grid is regulated by legal provisions. Access to the gas grid for biomethane plants is granted by the Gasnetzzugangs-Verordnung (GasNZV, Gas Grid Acess Ordninace). This ordinance ensures connection to the gas grid for all biomethane plants and biomethane transport in the same grid as natural gas with favourable conditions. This subsection describes all regulations relevant for the grid injection of biomethane in Germany.

7.2.1 Gas Grid Access Ordinance

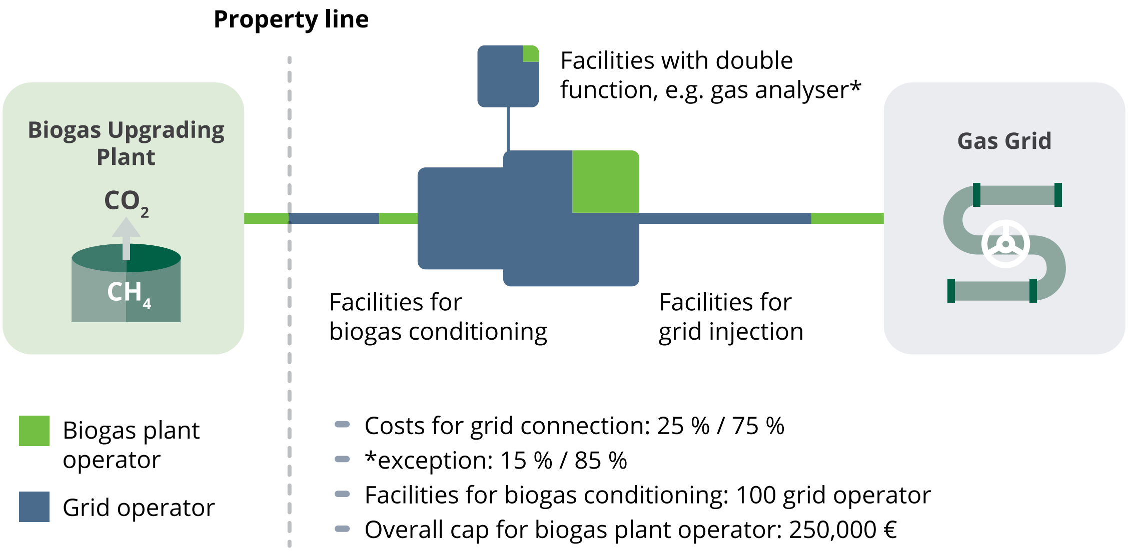
All plant operators who wish to connect their biomethane plant to the gas grid are granted grid access. The "Gas Grid Acess Ordninace" defines a reliable framework for (connection) time and cost. The cost is shared between the plant and gas grid operator. Figure 14 shows how the cost for the installations for the gas grid connection of a biomethane plant are split between plant operator and gas grid operator.

- The biogas plant operator covers all costs on its own property and for upgrading the gas.
- The grid connections between property, conditioning /upgrading facilities and the gas grid are shared, whereby the grid operator covers 75% and the plant operator 25%.
- The costs for the injection facilities are shared with the same rate (75%/25%)

There is a cost limit for the biogas plant operator at 250.000 € – the gas grid operator has to cover any costs exceeding this cap. Furthermore, the gas grid operator may have to provide a solution if biomethane injection exceeds grid capacity e.g. by enhancing the grid or transporting into a transmission grid.

The gas grid operator transfers his costs to the grid consumers through a grid fee.

Figure 15:
Overview of how the costs for the installations for gas grid connection of a biomethane plant are split between plant operator and gas grid operator.



- Costs for grid connection: 25 % / 75 %
- *exception: 15 % / 85 %
- Facilities for biogas conditioning: 100 grid operator
- Overall cap for biogas plant operator: 250,000 €

Source: Presentation W. Urban

7.2.2 Preferential grid access for biomethane plants and grid balancing rules

Upon injection, the biomethane is physically mixed with the natural gas in the pipeline. Physical separation of the biomethane and the grid gas is impossible afterwards. In order to allow transport of the biomethane inside the grid, the following fictional assumption has been introduced into the legal framework for the gas grid: The amount injected may be removed at any withdrawal point in Germany, if it has been tracked inside a mass balancing system. The preferential access to the gas grid in Germany means that any biomethane producer is entitled to inject the produced biomethane into the gas grid. Thus, fossil natural gas is displaced by biomethane wherever possible. The gas grid operator has to ensure that the grid can take up the injected volumes.

The general gas balancing rules for the around 600 gas grids in Germany grant simplified balancing for biomethane in the gas grid. The regulations in GasNZV, (Gas Grid Access Ordninace) allow biomethane injections and withdrawals to be balanced over a 12-month period. This is organised by a system of balancing zones which have to be operated by the market participants. For natural gas, this needs to be balanced on a daily basis. Additionally, the balance for biomethane needs to cover only 75%, in contrast to full balance requirements for natural gas. This results in simplified balancing, which allows biomethane owners long-term sales, as foreseen in the support schemes. This reflects the consideration that e.g. seasonal fluctuations in biogas production may differ from seasonal demand.

7.2.3 Reduced grid tariffs

Based on the idea that decentralised injection of biomethane reduces grid operation cost, the grid tariff has been reduced for biomethane plants. Biomethane plants with decentralised grid injection reduce the need for a national transmission grid due to reduced national and cross border gas transport volumes. In the relevant regulation (GasNZV) injected amounts may claim 0.7 ct/kWhHHV as "omitted grid costs", which contribute to the economic viability of plants. This regulation, however, is granted for the first ten years of operation of a plant only. Due to low biomethane market prices actually, the end of this tariff after 10 years of operation poses a severe threat for many of the operating plants.

Some standards have been developed by the gas grid branch, which have to be complied with: All German gas grid operators have commonly established a standard to unify contracts between Biomethane plants and gas grid operators, the "Kooperationsvereinbarung zwischen den Betreibern von in Deutschland gelegenen Gasversorgungsnetzen" (KOV, cooperation agreement between operators of German gas grid networks).

Furthermore, technical standards on the physical quality of gases are organised by the Deutsche Vereinigung des Gas und Wasserfaches (DVGW e.V. - German Association of Gas & Water Utilities) to ensure gas quality in the grids. The most important are the DVGW standard G260 and G262.

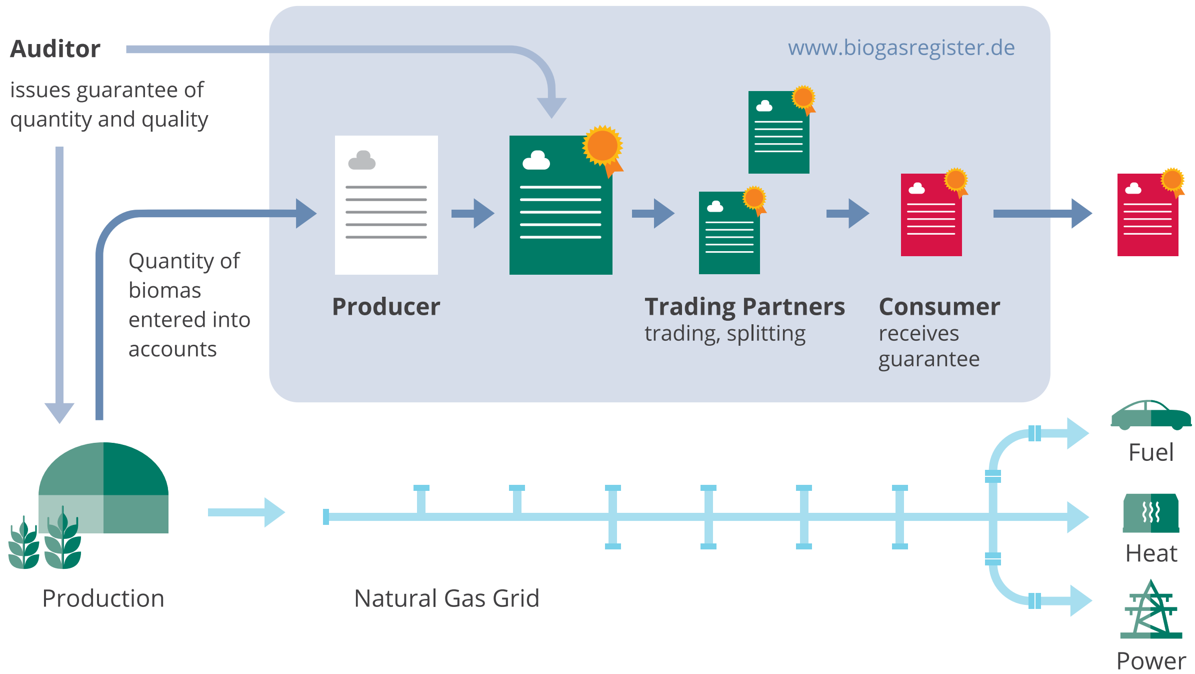
7.3 Biomethane trade and certification

All the mentioned support /obligation schemes require biomethane production to comply with specific requirements. The details of these requirements vary substantially between the different regimes and with their revisions.

In order to ensure compliance with the regulations for renewable gas use and certification, regular site audits are conducted. These are conducted as annual audits inside defined certification schemes. For biomethane production plants, which sell the gas for electricity production within the framework of the EEG, these take place in the first two months of the year, for the biofuel quota which is the incentive for biomethane use as vehicle fuel, the annual audits may be conducted any time of the year. An audit typically includes a site visit and a inspection of the substrate log.

The certification schemes for EEG are defined in German law. They are based on management scheme audits defined in the EEG. This scheme is based on the EU Eco Management and Audit Scheme (EMAS) and conducted typically by environmental auditors. Apart from this, sustainability criteria audits take place inside a European certification scheme defined in the Renewable Energies Directive (RED). According to this regulation, privately-owned certification schemes may be recognised by the European Commission for sustainability verification. For Germany, the two certification schemes REDCert and ISCC are in place. The audits are then conducted by certification bodies which apply the system's ruleset in the verification process.

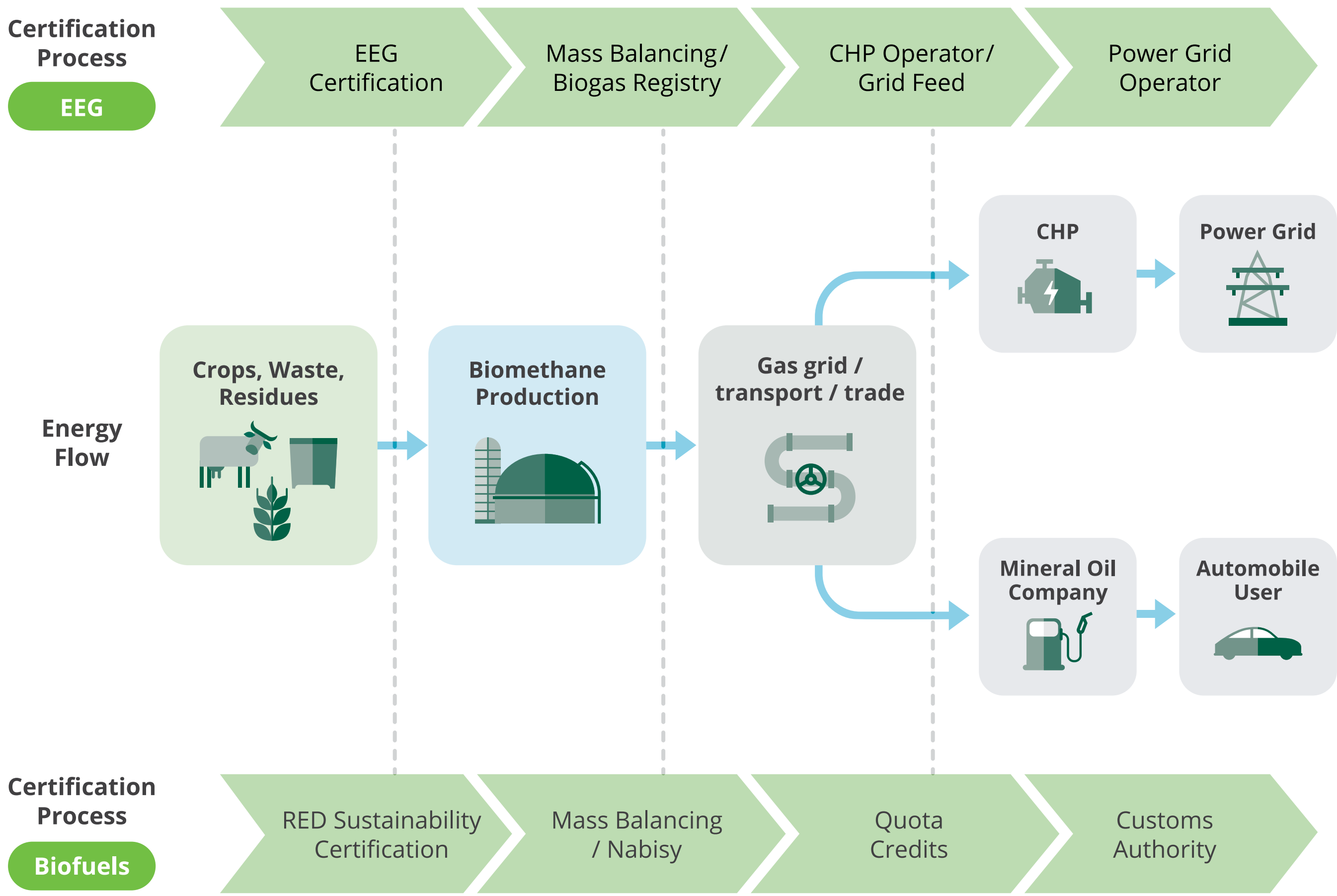
Figure 16: Certification structure and system for biomethane production and trade.



Source: (dena Deutsche Energie-Agentur, 2018)

The commercial distribution of biomethane is usually carried out by specialised trading companies. In order to track the renewable and certified biomethane streams separately from the fossil natural gas streams, several biogas registries are used in Germany. Their main task is to track biomethane amounts (mass balancing method) to allow a virtually separate transport in the gas gird and to avoid double selling of biomethane amounts. The most important registry for biomethane is the German Biogas Registry operated by the German Energy Agency: www.biogasregister.de, see Figure 15. For sustainable biofuels (transport fuel obligation) the use of the nabisy registry (Bundesanstalt für Landwirtschaft und Ernährung, 2020) is obligatory. It is expected that both registries will be merged in the future.

Figure 17: Energy flow and certification/cash flow for the biomethane certification and incentive system.



7.4 Biomethane for heating

Several obligation schemes define rules for the heat supply in Germany. These obligations aim to reduce fossil energy consumption for new or renovated buildings. In Germany, the focus in buildings is on increasing building efficiency, esp. thermal insulation. However, house owners are free to apply renewable energies to achieve this, for example with one of the following:

- solar thermal energy
- wood-fuelled heating
- heat pumps
- plant oil
- biomethane

The first national obligation for heating buildings with renewable energies was the Erneuerbare Energien Wärme Gesetz (EEWärmeG – Renewable Energy Heat Act). This has recently been replaced by the Gebäude-Energie-Gesetz (GEG – Building Energy Supply Act), which will enter into force by the end of 2020. Biomethane is one option to fulfil the required combination of minimum energy efficiency and minimum application of renewable energy for heating. The effects of the new regulation cannot be foreseen yet.

Some of the Federal States have also enacted their own, and more progressive, heating obligations. The federal state of Baden-Württemberg has a progressive ruling on the same matter in their “Erneuerbare Wärme Gesetz” (EWärmeG – Renewable Energy Heat Act), requiring a minimum of 15% heating energy demand reduction or a renewable heat supply in case of building renovations or replacement of the heating system compared to the situation before renovation.

In all cases, biomethane offers a simple solution for reaching the stipulated renewable energy targets. Biomethane from the gas grid can be used in conventional gas heaters without any changes to the equipment. House owners only need to purchase a biomethane gas product instead of a natural gas product.

7.5 Biomethane for power generation

The largest factor for spurring the development of biomethane plants in Germany was the Renewable Energy Sources Act (EEG), which first granted support to power generation from biomethane in 2004. In 2009, a revision of the law granted even more generous support for biomethane and triggered strong growth of the biomethane sector. However, the support for biomethane was reduced in revisions of the EEG in 2012 and 2017, which resulted in a stagnation of the number of biomethane plants. Once put in operation, a biomethane based CHP unit is guaranteed to achieve the high feed-in tariffs for 20 years as a solid basis for an investment decision. Thus, most of the plants are still in operation, while no new plants are being built (see Figure 14).

Throughout the revisions, the EEG has changed from a feed-in tariff system to a feed-in premium system. In its present version, the premium level is determined in a public tendering process. Achievable feed-in tariffs today are around 14 ct/kWhel, which do not encourage biomethane use for electricity production anymore. However, the tariffs since 2004 still apply for existing plants until 20 years of operation are finalised. Therefore, it is to be expected that for the coming years electricity production is still the largest market for biomethane.

Spotlight 6

Rules for feed-in tariffs for electricity from biomethane 2004-2014

In the older versions of the EEG up to 2014, a differentiated bonus system would grant CHP operators a higher premium, e.g. for the following:

- smaller plants
- upgrading & injection of biomethane
- using certain substrates, e.g. organic waste, or slurry

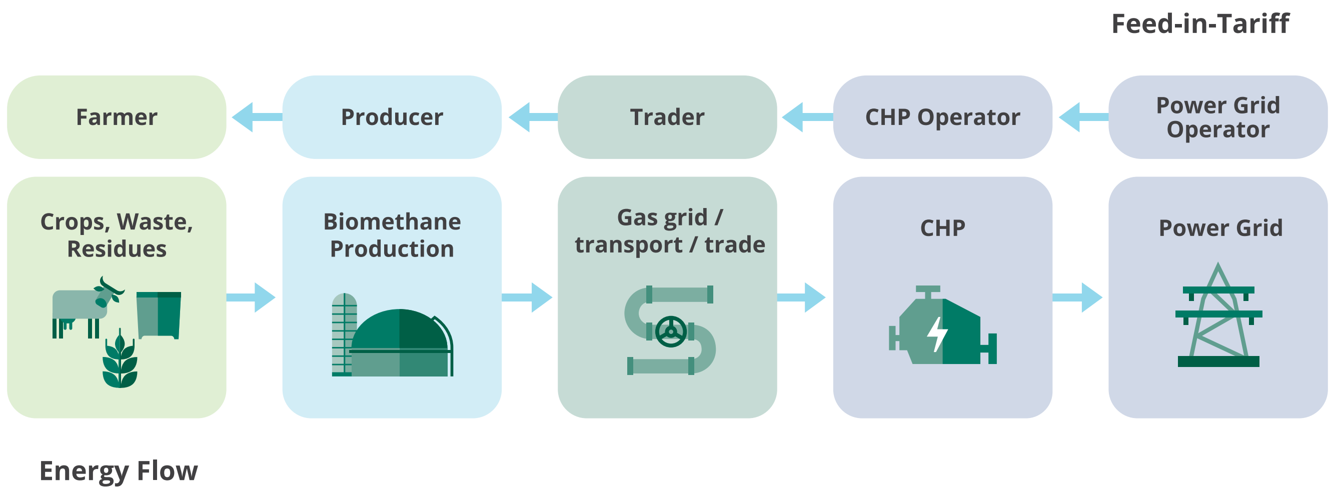
Meanwhile, the bonus system has been phased out in order to reduce the overall costs of the EEG biomethane. The support was focused increasingly on only the most cost-efficient production. The following table summarizes the support scheme in numbers.

Feed-in Tariff	Minimum	Typical	Maximum
Base tariff	6 ct/kWh$_{el}$ (Operational start up to 2014 for plants > 20 MWel capacity)	13 ct/kWh$_{el}$ (Operational start up to 2014 for plants in the range of 0.5 MWel capacity)	14.88 ct/kWh$_{el}$ (Operational start 2017 without any additional tariffs)
Bonus tariff for energy crops and use of advantageous substrates, e.g. manure	0 ct/kWh$_{el}$ (Operational start up to 2014 for plants > 20 MWel capacity or plants with waste only)	6 ct/kWh$_{el}$ (Operational start up to 2014 for plants 500-5,000 kWel capacity based on energy crops and manure)	8 ct/kWh$_{el}$ (Operational start up to 2014 for plants <5,000kWel capacity based on substrates from nature conservation)

Bonus tariff for biogas upgrading	0 ct/kWh$_{el}$ (Operational start up to 2014 for CHP using biomethane from a plant >1,400 Nm³/h biomethane production capacity)	2 ct/kWh$_{el}$ (Operational start up to 2014 for CHP using biomethane from a plant <700 Nm³/h biomethane production capacity)	3 ct/kWh$_{el}$ (Operational start -2014 for CHP using biomethane from a plant <350 Nm³/h biomethane production capacity)
Total	6 ct/kWh$_{el}$ (no such plant exists)	21 ct/kWh$_{el}$	23 ct/kWh$_{el}$ (the highest tariffs above cannot be combined, this is a mixed calculation)

Besides the bonus system, the EEG also introduced additional requirements for biomethane production: The maximal allowed power consumption of biomethane upgrading was set to 0.5 kWh/Nm³ in order to support only efficient biomethane production. Fugitive methane emissions are limited to 0.2 % of total production considering the strong greenhouse effect of methane. Heat demand in the production process (especially heating of the fermenter) must be covered from renewable sources.

Figure 18: Incentive structure for biomethane for CHP units



Several regulations deal with agricultural substrates for biomethane production. The support of substrates has been subject to radical changes throughout the years of support. In the first years of support in the EEG scheme, there was a bonus incentive for the use of agricultural crops. A large debate on the consequences of intensified bioenergy agriculture eventually led to a complete roll-back of this support. In a first step, the amount of maize was limited to 60% in one fermenter. The bonus was only granted for waste and residue streams and sustainability criteria.

Another support scheme to grant subsidies for power and heat cogeneration from biomethane is the Kraftwärmekopplungsgesetz (KWKG – Cogeneration Act). Recent revisions included biomethane as an option for innovative renewable energy concepts, but due to the relatively low incentives no impact on biomethane utilisation has been observed so far.

The general support mechanism works according to the following principle: Based on the measured kWh injected into the electricity grid, a feed-in premium is granted to the operator of the plant. The direct payments to the plant operators are done by the grid operators themselves. These payments are shared equally among all consumers of the grid by means of a levy.

In the case of the EEG, the strong growth in renewable energy plants has caused this levy to rise and thus to become a substantial part of the energy bill. This led to attempts to cut down costs, which eventually caused the stagnation of construction of new biomethane plants.

EEG support in CHP has made biomethane grow in Germany. As a result of the decreased support payments, biomethane growth nowadays needs to be based on more complex business models with more focus on GHG emissions.

7.6 Biomethane as vehicle fuel

The German biofuels quota (as regulated in the "Bundes-Immissionsschutzgesetz (BImSchG, Federal Immission Control Act) requires all companies selling engine fuels to include a portion of renewable fuels in it. The regulation transposes European legislation into German law and allows recognition of biomethane as fuel for CNG vehicles.

The quota system is designed in a market-based approach: Companies producing renewable fuels receive a quota credit for each volume of fuel produced. Mineral oil companies selling engine fuel need to obtain quota credits in the defined quota of their fuel sales. The market for quota credit works as described in Figure 19. Operators of filling stations certify their sold amounts of biofuels (e.g. biomethane) to the customs authority and receive quota credits for the GHG savings associated with it. Then they can transfer /sell their credits to mineral oil companies who in their position have to present these credits to the same authority in their annual reporting obligation.

Figure 19: Incentive structure for biomethane for as a vehicle fuel

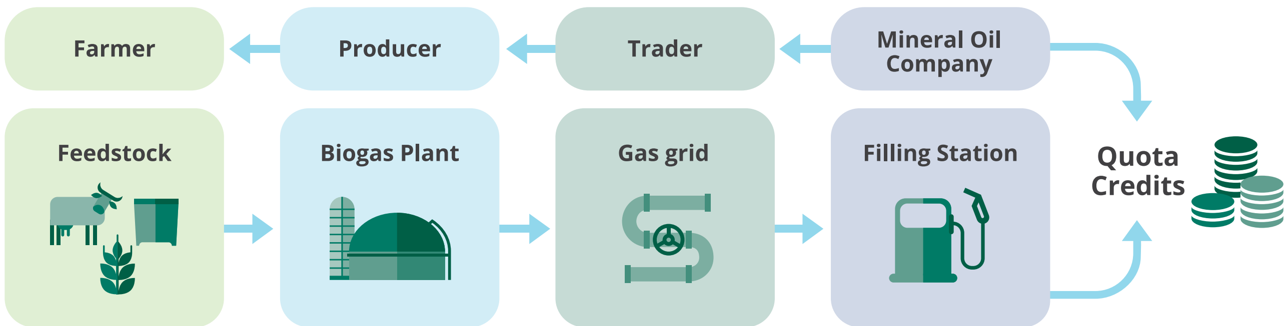
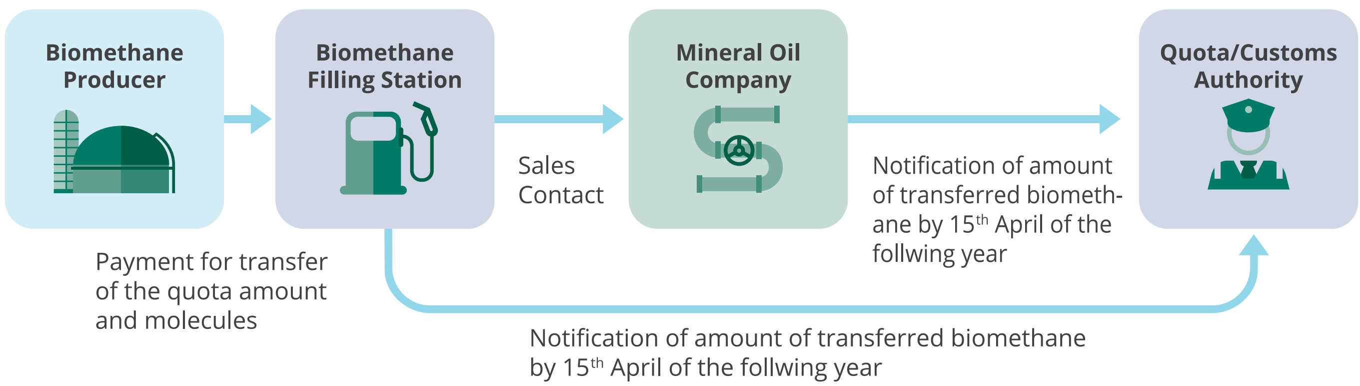


Figure 20: Overview quota system.

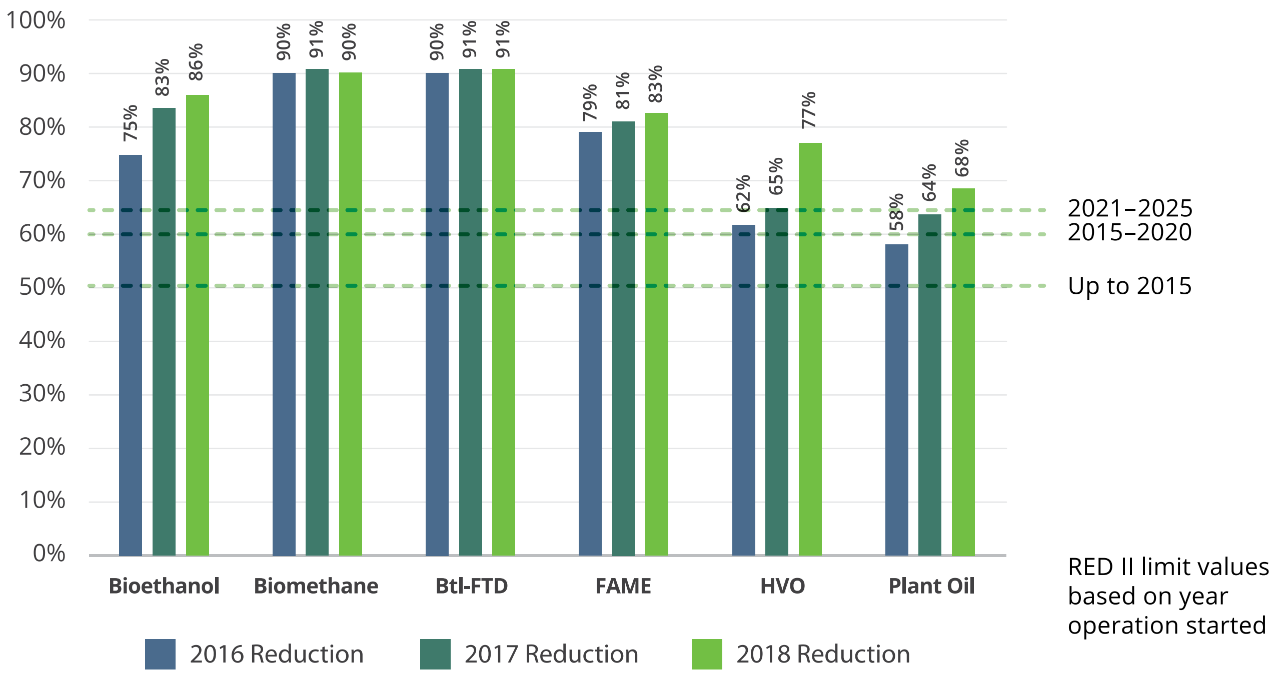


Source: Fachverband Biogas (www.biogas.org)

The German regulations include a calculation of the amount of quota credits granted. The quota credits are granted in relation to the greenhouse gas savings, which means that a fuel with higher GHG savings achieves a higher quota and therefore a higher price on the market. The calculation of greenhouse gas emissions savings (in relation to fossil fuel) is determined by a life cycle analysis of the production path. In addition to the general biofuel quota, a "sub-quota" for advanced biofuels with special provisions needs to be fulfilled. Biomethane from waste and residue materials are eligible as an advanced biofuel and thus achieve increased accounting of quota credits.

Figure 21 shows average GHG savings per biofuel type as reported by the German registry for sustainable biomass and the threshold values based on the date production in a plant started (green dotted lines). Threshold values mark the minimum GHG savings which have to be achieved with the fuel produced from a biofuel production plant compared to the standard emission value for fossil fuels given by law in the Renewable Energy Directive (RED). Rising threshold values (50%-65% GHG reduction) show how GHG savings from biofuel production need to be further reduced in the future. Biofuels below this threshold are not eligible to be accepted biofuels. In comparison with other biofuels, biomethane has a high GHG reduction rate. This advantage may increase the demand for biomethane in the transport sector in the future.

Figure 21: Emission reduction of biofuels according to fuel type.



Source: BLE (BLE Bundesanstalt für Landwirtschaft und Ernährung (Hrsg.), 2019)

The deployment of biomethane as transport fuel in Germany is limited by the small overall demand of natural gas as a vehicle fuel. In order to increase this demand, the government subsidises the purchase of NGVs and introduced road toll reductions for CNG and LNG trucks. Germany as a traditional gasoline and diesel country thus incentivises the development of a new fuel type. Biomethane may profit from this development.

7.7 GHG emission requirements and incentives

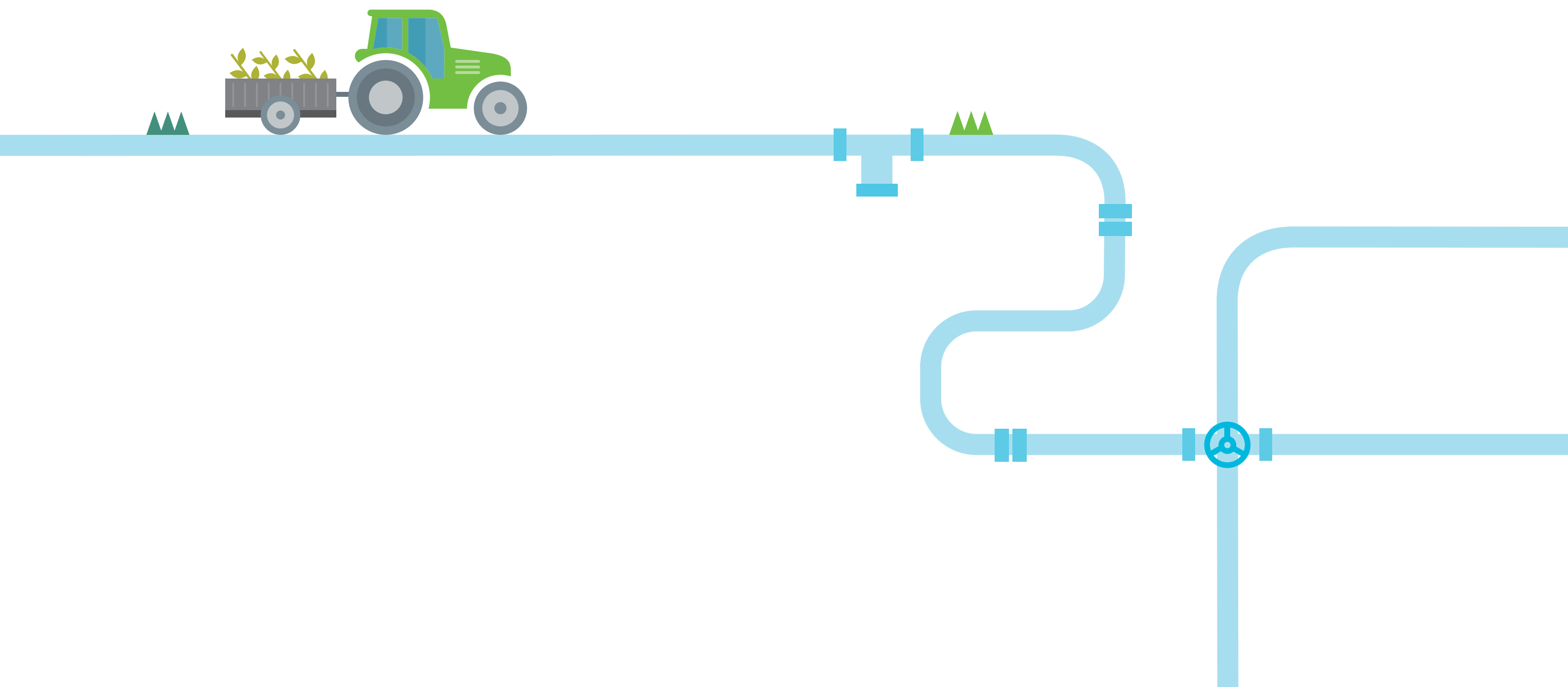
As described above, the biofuels quota in Germany incentivises biomethane based on the GHG saving potential. As an orientation value, GHG emissions from using biomethane as an energy supply range between 36 -158 g CO_2equ /kWh as reported by (dena Deutsche Energie-Agentur, 2018) and (UBA Umweltbundesamt, 2016). In the calculation methodology provided by European law, waste and residues as substrate lead to lower emissions, biomethane from slurry may even result in negative emissions due to omitted atmospheric emissions of CH_4 and other greenhouse gases. Besides the substrates, a storage facility for fermentation residues may reduce GHG emissions in the production process up to up to 10%.

Besides GHG emission saving incentives, two carbon taxation mechanisms may also be relevant for biomethane.

The European Emissions Trading Scheme (EU-ETS) governs the reduction of overall European greenhouse gas emissions by a cap-and-trade system. For each ton of greenhouse gas emitted, the emitter needs to purchase an EU emission allowance (EUA). If not, a penalty payment of more than 100€/t applies. The amount of EUAs is reduced every year. These allowances are tradable on the market. The idea is to induce emission reduction at the economically most efficient spots. In this mechanism, a company may choose to reduce emissions or to buy more EUAs on the market. The EUA price is determined on the market as a result of the demand in Europe. In the EU-ETS, biomethane is considered a carbon-neutral biomass, even if it is transported through the gas grid. This enables an application for biomethane to replace natural gas. Due to the comparably low carbon emissions per kWh of natural gas, the impact of a carbon price is low compared with more carbon intensive fuels like lignite or coal. Present ETS prices have an impact of about 0.2 ct/kWh on natural gas.

Germany is at present in the middle of establishing a separate new national emissions trading scheme. This system can be described as a carbon-based taxation of fuel sales. At the moment of selling a fuel (e.g. natural gas) to a final consumer, a carbon price has to be paid. For the years up to 2025, a fixed price has been stipulated, with an increasing level from 25€ in 2021 to 55€ in 2025. This will raise natural gas prices by around 0.5-1 ct per kWh.

Both GHG taxation systems have virtually no impact on biomethane at the present time. The carbon price has a stronger impact on more carbon intensive fuels, e.g. lignite. The historic and expected price ranges in both systems will not suffice to induce a fuel shift from natural gas to biomethane on their own. However, they may add their bit to the overall competitiveness of biomethane.

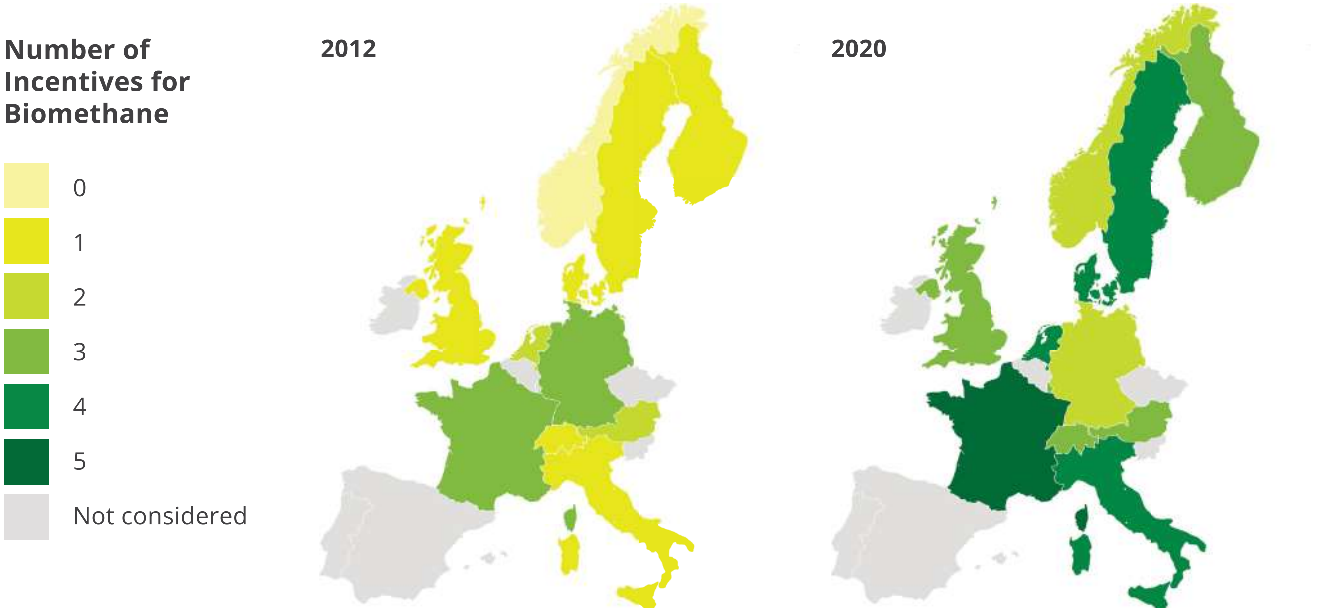


8

Attractive biomethane production & use conditions in other countries

Germany was among the first movers in Europe to incentivize biomethane production and many countries have learned from the German experiences. Complexity of the German funding schemes is high, but triggered a strong industrial development in a way such that in some years almost 50% of all biomethane plants worldwide were under operation in Germany.

Figure 22: Development of incentives for biomethane in Europe between 2012 and 2020.



Source: Sia Partners and own research

Many other countries have incentives for biomethane production and use nowadays. Table 7 indicates the main European countries with incentives in effect in 2020. The mode of action of the different incentives is described in the following pages.

Table 7: Overview of incentives used in selected European countries for biomethane.

European countries	Priority gas grid access	Feed-in tariffs for biomethane	Certificates and/or quotas	Investment subsidies	Tax Exemptions
Germany	✓		✓		
Austria	✓	✓	✓		
Denmark		✓	✓	✓	✓
Finland			✓	✓	✓
France	✓	✓	✓	✓	✓
Italy	✓	✓	✓	✓	
Norway				✓	✓
Great Britain		✓	✓		✓
Sweden		✓	✓	✓	✓
Switzerland		✓	✓	✓	
Luxemburg	✓	✓		✓	

Source: Sia Partners and own research

Priority gas grid access

Priority gas grid access gives any producer of biomethane the privilege to inject his gas into the gas grid as long as the gas grid capacity is sufficient. There are differences between the countries concerning the efforts gas grid operators are required to make in order to make the injection of biomethane technically possible in case of limited gas grid capacities. In every country with priority grid access for biomethane, fossil gases must be reduced first when a biomethane producer injects biomethane into the grid. Priority gas grid access is of high importance to reduce investment risks.

Feed-in Tariffs

A feed-in tariff provides remuneration per unit of renewable energy injected into the public gas grid. Authorities define and guarantee the tariff for a specified time period of between 10 and 20 years. It is typically connected with guaranteed grid access and payment levels are typically based on the biomethane generation cost. The level in most European countries is in the range between 7 and 12 ct/kWhHHV. They vary by project size, type of substrate for the biomethane production and other criteria. Feed-in tariffs have the advantage that the producer does not have to be involved in marketing and sales. This is the most efficient driver for rapid biomethane development, which has been seen in some countries e.g. France (0.7 TWh production capacity within 5 years), Denmark (1.75 TWh production capacity within 6 years) and UK (4.0 TWh production capacity within 6 years).

Quota/green certificates

In a quota/green certificates system, the production of renewable energy is encouraged by an obligatory target. Such a target can be a share of renewable energy in the energy mix or a minimum GHG reduction and is comparable with CO_2 emission trading systems. Producers of biomethane benefit by selling their energy to the grid at market price and by selling certificates on the green certificates market.

Investment subsidies

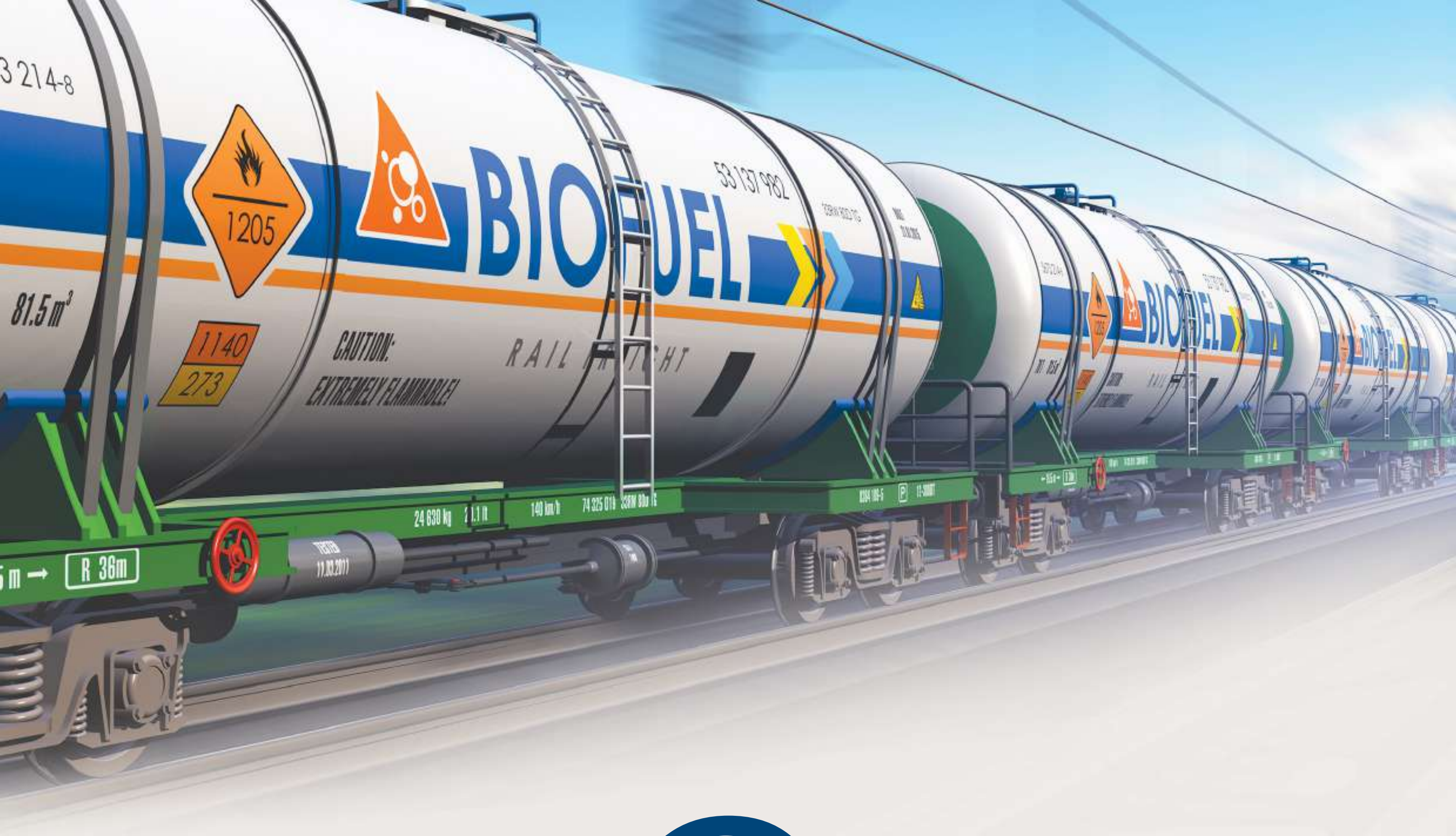
Investment subsidies reduce the investment risks and reduce barriers for investments, in particular for municipalities, but also for industrial players. In some countries, such as Sweden, they are the same conditions for all biomethane plants. In other countries the plants are bound to innovative solutions or specific regional development. Investment subsidies are typically payed as a percentage of the investment cost in the range of 10 to 40% - sometimes only for the innovative part of a plant. Due to the fact that operating costs play a much greater role in the production cost of biomethane in most cases, subsidies are of minor importance for biomethane market development.

Tax exemptions

Tax exemptions or reductions are usually additional (and minor) support systems. Biomethane generation or sales can receive certain tax exemptions (e.g. carbon taxes, energy taxes) as compensation and to add to its competitiveness in the energy or vehicle fuel market.

Market development support

National or regional governments have the ability to clearly support a market development with an unlimited number of different actions. Since they are not always directed solely towards biomethane they are not considered in Table 7. This can include strategies to strengthen CNG and LNG (compressed and liquified natural gas) as vehicle fuel, which is happening all over Europe with strong subsidies for filling stations and the substitution of diesel-based cars, busses and trucks as well as maritime vessels. This can also be binding requirements for renewable heating for new buildings as prerequisite for building permits. It can also be free parking or free use of bus lanes in cities for biomethane driven vehicles. Another example is public procurement guidelines e.g. for heat supply or purchase of new vehicles – when authorities serve as good examples others will follow. Last but not least, a market development incentive can also be a support of marketing and branding strategies as well as positive communication towards the possible end user groups.



9

Business models for biomethane production and use

The different market-based approaches in the support schemes enable the development of different markets and niches in the biomethane value chain. This subsection describes the main business models based on the EEG and the biofuel quota (as introduced in the previous chapters). Common to the models is that the final revenue needs to cover all steps along the value chain, which are:

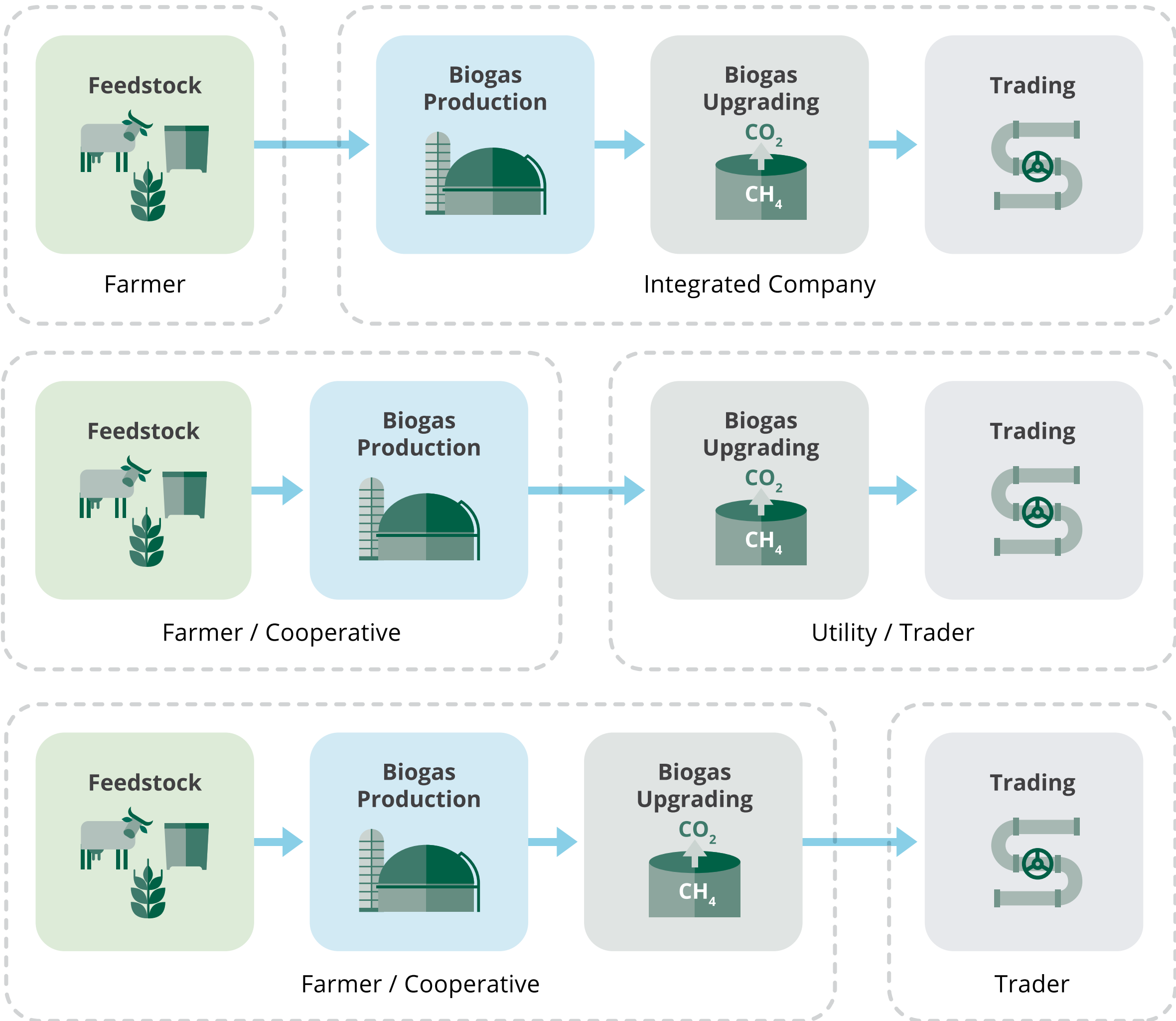
- waste collection/agricultural business
- biogas production (including certification)
- biogas upgrading to biomethane & injection
- gas grid transport (including mass balancing and balancing management)
- biomethane trade
- gas delivery to the final consumer

More servicing business models accompany the biomethane industry, like specialised certification bodies, metering services, or the planning or construction of new biomethane plants.

9.1 Combined heat and power generation

The basic business model for biomethane based on the EEG's support scheme spans the value chain between agriculture/waste collection and the final conversion of the biomethane to electricity and heat in a CHP unit. A CHP operator receives biomethane from the gas grid. The CHP operator receives the support (feed-in tariff per kWh electricity generated) and, in the case of a feed-in premium, also gains revenue from electricity sales. The CHP operator may gain additional revenue for from sale of heat. Figure 23 visualises some the EEG business model constellations.

Figure 23: Examples of EEG business models



On the German market, different business integration models have developed throughout the years in the context of the EEG: There are specialised companies covering only parts of the value chain, e.g. trade of biomethane, gas grid transfer, or operation of plants. Often, the biogas production is integrated into an agricultural company. The biogas is then usually sold "at flange" or after injection (depending on the allocation of the upgrading process) and distributed by one of the few specialised biomethane trading companies on the energy market in Germany but also cross border. Final sale to consumers, especially for green gas products, is done by energy suppliers. Some smaller actors are regionally-based and may be part of an integrated municipal supply. On the other hand, a few large companies and corporate groups exist, which include all steps from production until final sale. As a result of the stagnating development, a consolidation of actors has taken place; fewer and larger actors dominate the market meanwhile.

9.2 Biomethane as vehicle fuel

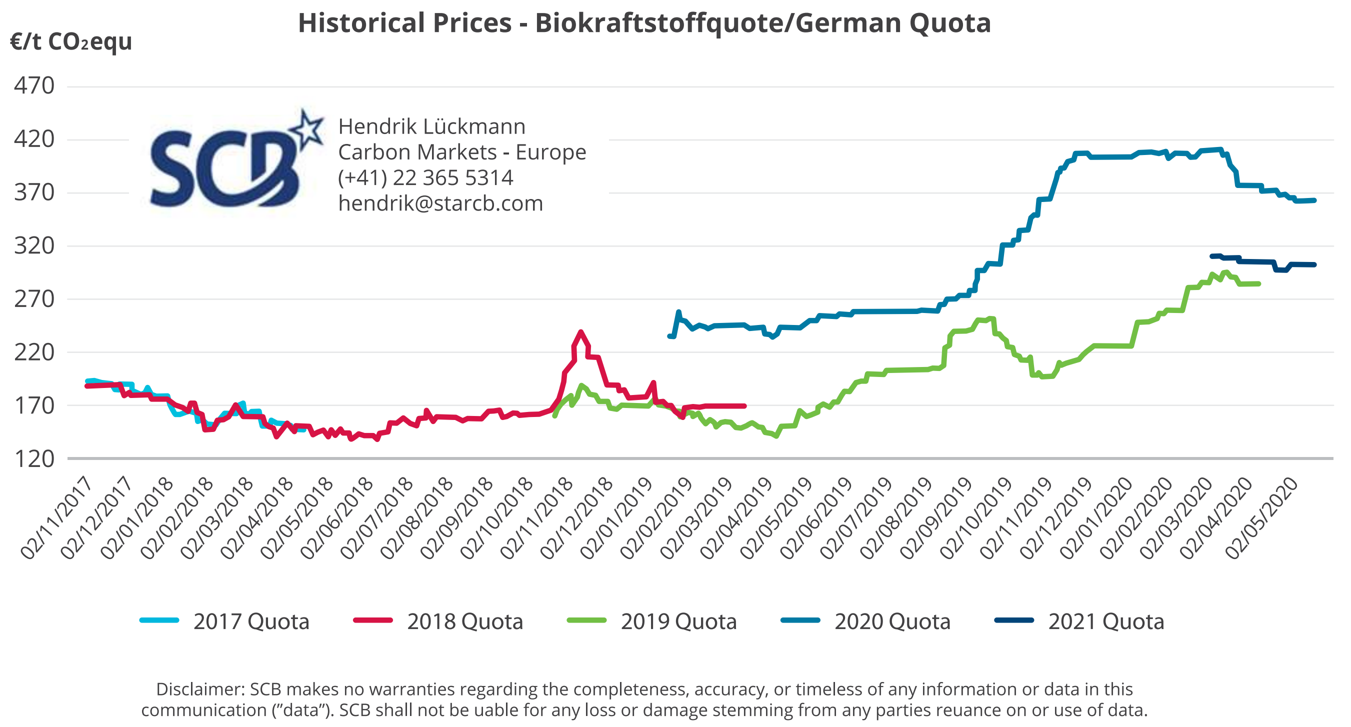
The basic business model for the biofuel quota requires the producer (or trader) to contract filling stations to sell biomethane as engine fuel. It may be sold as biomethane or as a biomethane/natural gas blend. For the biomethane sold, quota credits are granted, which are required by mineral oil companies (see subsection 7.6). If such a company cannot provide enough quota credits, it must pay a high penalty, which is calculated with 470 € per t GHG-emission savings, which have not been realised. This penalty defines a (rather high) price cap for the quota credit range and triggers demand for quota credits. The offer of all biofuels meets the demand of all mineral oil companies which defines the quota credits price to be achieved. As seen in Figure 24 the upper range of quota prices developed in the last years from 200 €/t in 2017, over 250 €/t in 2018 to 420 €/t in 2020.

The revenue from selling the biomethane fuel at the filling station and the revenue achieved for the quota credits must cover the necessary steps (see Figure 24) in the value chain.

The **risk structure** of the two models is very different:

- The EEG business with a fixed premium or tariff for 20 years of operation granted by German law, bears comparably low risk for investors. The feed-in premium model includes slightly more risk relating to electricity sales. If all participants on the value chain remain in business, this may be a robust model for the duration of the support.
- The biofuels quota business model bears higher risk in many aspects. Gas stations are facing competition with regard to price and amounts of their fuel sales. Furthermore, the biofuel quota price is influenced by many factors, many of them lay outside the biomethane business. The biofuels market is a European market and Is based on worldwide supply chains.

Figure 24: Overview of the price development for the German biofuel quota.



Source: SCB Brokers SA, H. Lückmann

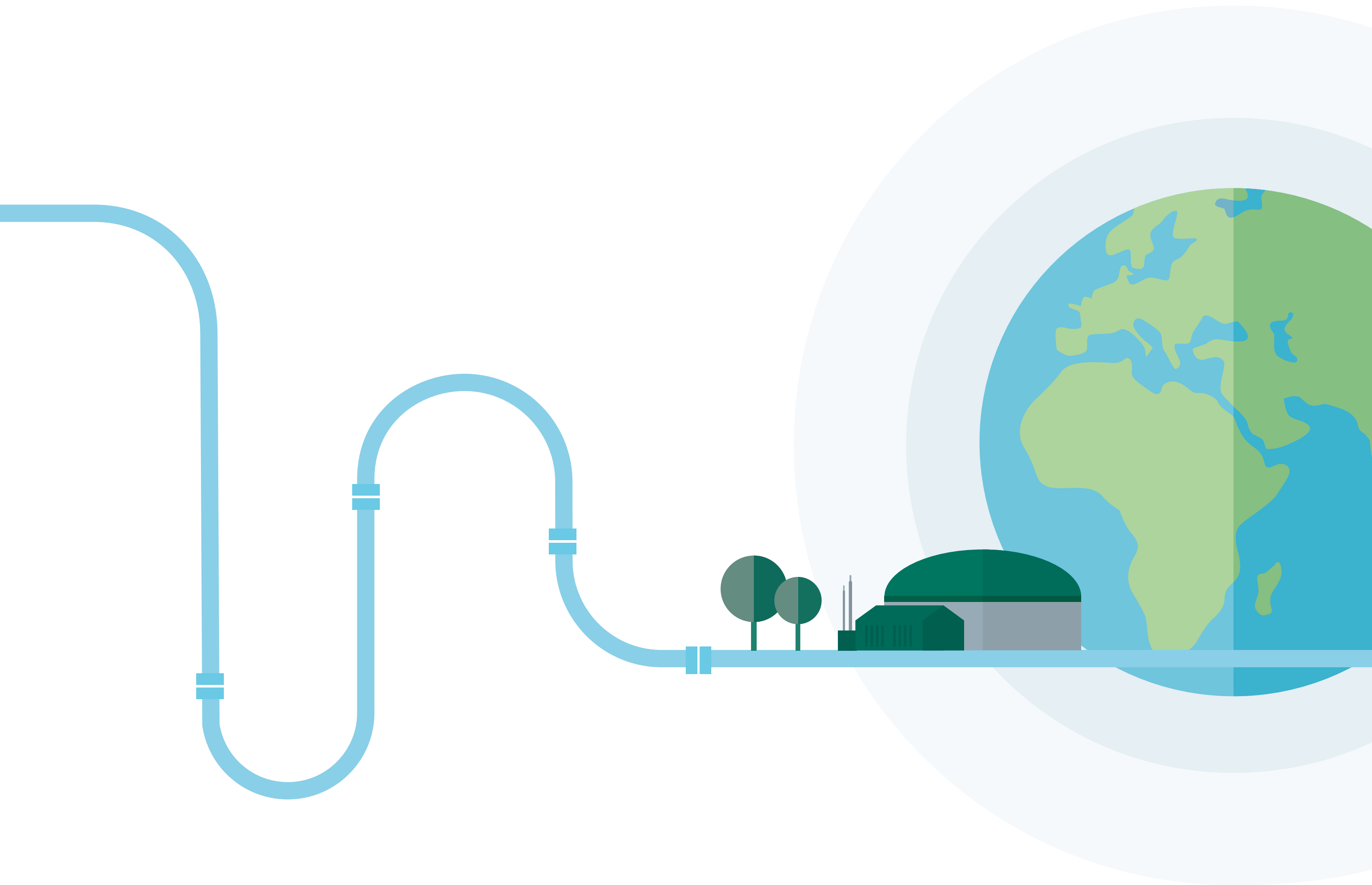
10

Challenges in a politically induced renewable gas market competing with strongly fluctuating fossil energy prices

As of today, the cost of fossil energy is historically low. Renewable energy production costs - especially for wind and solar power production - are steadily falling, but have a clear minimum where a further reduction will be hard to achieve. Biogas and biomethane production is connected to manpower, biomass and digestate logistics and the plants have to be integrated regionally. Continuous technological innovation is taking place, but ground-breaking technological cost reduction is not to be expected. Investments into biomethane technology are typically done by small and medium enterprises, which have a limited ability to compensate financial risks. They need a secure basis for return of investment.

For implementation of incentives for biomethane production and use the target group of these incentives needs to be clearly identified as well as the pathway, in which the incentives take effect for the biomethane producer. If rapid market growth is the target, a very reliable, robust and crisis-proof model is necessary. Due to greater operational costs compared with the share of investment costs, subsidies for investments do not seem to be the preferred incentive. In contrast, feed-in tariffs or feed-in premiums seem to be the most effective measures to start a market development – whereby such systems are most expensive. They must be based on the real production cost of biomethane. After establishment of a biomethane market, robust green certificate models or models which require a minimum biomethane quota can be established and reduce the dependency on governmental support. But they should still be robust in crisis situations and offer existing biomethane production units, which were established under conditions of some years ago, the chance to adapt and survive.

The main driver of investments is a reasonable return on investment combined with a positive contribution to GHG mitigation. To secure both, incentive systems should be based on a GHG reduction approach and offer long term financial security, which means rules that are – independent of future adaptions – reliable for an investment for at least 10 years of operation.



11

Technical norms for the relevant technologies

Along the value chain of the biogas and biomethane plant there are technical norms, which regulate work safety, environmental protection and product quality. The following is a brief overview of the norms and links to more detailed information can be found in Section 15.

Substrates are regulated in different manners depending on their source. The Circular Economy Law (Kreislaufwirtschaftsgesetz) categorizes waste, which can have an influence on the treatment possibilities and requirements. The Biomass Regulation (Biomasseverordnung) is relevant for the definition of biomass, for example for the purpose of the feed-in tariff amount.

Some waste has safety issues, which have to be regulated. Municipal organic waste or waste from food production have to be pasteurized in accordance with the BioAbfV Organic Waste Ordinance. The ordinance contains the definition of types of food waste, requirements concerning pollutants as well as technical requirements concerning hygienization. There are different methods for guaranteeing a hygiene product, such as pasteurization tanks (70° C for at least one hour) or post-fermentation composting, which also achieves temperatures around 70° C over a longer period of time. The Animal By-Product Disposal Law (TierNebG) defines the precautions to be taken with regard to animal waste, such as from slaughterhouses.

The main issue with agricultural substrates is the storage, especially for manure. If manure is not stored in a covered tank, the substrate begins to ferment and the methane is released into the atmosphere. Accordingly, it is the BImSchG German Federal Immission Control Act, which regulates the storage. In this context it is also the amount of substrates treated, which determines how detailed the permitting process for the plant will be.

Biogas production plants must comply with numerous **safety and emission** regulations. Due to the nature of gas production it is self-evident that among the main hazards of biogas production is the leakage or potential explosiveness of biogas. TRAS 120 lies out the specific areas, for example where there is an explosive hazard. It regulates which precautions have to be taken and how often inspections are necessary. In addition, the GefStoffV Hazardous Material Ordinance states which materials, such as certain process additives, have to be controlled and the AwSV Ordinance on the handling of water-endangering material from industrial plants regulates which precautions are to be taken so that contaminants from the plants do not make their way into water bodies. More information can be found in Section 15.

CHP units must comply with emission related regulations. The Immission Control Act has 44 ordinances, which cover various emitters. The 44th BImSchV Federal Immission Control Ordinance deals with combustion motors, such as CHP units and provides limit values for units < 1 MW, e.g. CO, NOx, NH3, SOx, dust, formaldehyde. Moreover, the Technical Guideline for Air Quality (TA Luft) defines additional criteria for emission limitation regarding organic carbon release (excluding CO2).

In order to ensure that **biomethane** is a standardized product for trade as well as gas pipes and equipment are protected from contaminants and corrosion there are norms, which are developed on several levels – from the European Committee for Standardisation (CEN) to national authoritative associations, such as the German association for the gas and water industries DVGW (Deutscher Verein des Gas- und Wasserfaches e. V.). The DVGW develops industrial standards in its technical committees, which are used as a basis in German and EU regulatory framework.

Biomethane is a gas that mainly consists of methane, which is obtained either by processing biogas or by methanating bio-synthesis gas. After upgrading by removal of chemical and mechanical substances such as carbon dioxide, hydrogen sulphide, volatile organic hydrocarbons and water, biomethane is suitable for use as a fuel. Minimum requirements for the quality of biomethane for fuel use are defined in DIN EN 16723-2: 2017-10 "Natural gas and biomethane for use in transportation and biomethane for feeding into the natural gas network - Part 2: Specifications for fuels for motor vehicles". A limited proportion of accompanying substances is permitted, which must usually be reduced to a minimum before the biogas upgrading process. The accompanying substances mentioned above are as follows:

- Total volatile silicon 0.3 mgSi / m^3
- Hydrogen 2 mol%
- Oxygen 1 mol%
- Hydrogen sulfide and carbonyl sulfide (as sulfur) 5 mg / m^3
- Total sulfur (including odorization) 30 mgS / m^3
- Amine 10 mg / m^3

Biomethane for use as a fuel must be free of contaminants, apart from the "de minimis" levels of compressor oil and dust-related contaminants.

The content of higher hydrocarbons is limited by the hydrocarbon dew point. This should be minus 2° C for the range from 0.1 MPa to 7 MPa absolute pressure.

Compliance with the quality criteria for CNG as a fuel must be certified once when commissioning the system, e.g. by the TÜV.

Conditions for the quality of the biomethane fed in apply in particular to the feed into the gas grid. These relate to limit values of the various gas components and the technical characteristics (calorific value and Wobbe index – see T).

The concrete requirements are laid down in the gas network access regulation in the DVGW worksheets (in particular G260, G262 and G685). By processing and conditioning the biomethane before it is fed into the gas network, these limit values must be observed.

Table 8: Requirements for injection into the German gas grid according to the working paper G260 of the DVGW (Deutsche Verein des Gas- und Wasserfaches e.V.)

Limit values (according to DVGW Arbeitsblatt G260)			
Parameter	**Units**	**"low" gas grid**	**"high" gas grid**
CH_4	Mol%	≥ 90	≥ 95
CO_2	Mol%	≤ 10	≤ 5
H_2S	mg/m³	5 (temporarily 10)	
O_2	%	in dry grids 3, in humid grids 0.5	
H_2		no specific value	
Total Sulfur	mg/m³	30 (temporarily 150)	
Mercaptan	mg/m³	6 (temporarily 16)	
Water content	mg/m³	with grid pressure up to 10 bar ≤ 200, with grid pressure larger than 10 bar ≤ 50	
Wobbeindex ($W_{S,N}$)	kWh/m³	10.5 – 13.0	12.8 – 15.7
Relative density	d	0.55 – 0.75	
Connection pressure (p_{an})	mbar	18 – 24	
Fuel value ($H_{S,N}$)	kWh/m³	8.4 – 13.1	

Stricter threshold values have to be realised when it comes to biomethane injection into high pressure European transport grids, what is defined by EASEE and values are given in the table below.

Table 9: Requirements for injection into the European transport gas grid according to the EASEE rules.

Limit values (according to EASEE)			
Parameter	**Units**	**min**	**max**
Wobbeindex ($W_{S,N}$)	kWh/m³	13.6	15.81
CO_2	Mol%		2.5
O_2	Mol%		0.001

12

Applicability of German experience to China

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12.1 Lessons from Germany's biomethane development

Application should go beyond electricity generation

Biomass energy is the only renewable energy that can be directly converted into electricity, gas, heat, fuels and other energy-related products. Digestate and slurry produced from biomethane production could be used as ingredients for organic fertilizer. Across Europe, biomethane industry since its inception has been designed to develop in large scales to mitigate fossil fuels needs, follow a high added-value trajectory, and grow with a favorable market environment for the supply side.

With the advancement of renewable energy power generation technologies, the cost of wind power and solar PV power continues to drop. It is predicted that by 2025, their cost will be lower than that of coal electricity. In contrast, biomass energy-based electricity generation is less cost effective and subsidies for the renewables feed-in tariffs in China are constantly paid in arrears. Therefore, exploring the usage scenarios of biomass energy beyond power generation, as well as its circulation and cascaded use, for example tapping into the huge market potential of organic fertilizers production, could be a new and more sustainable way forward for biomass energy growth.

Need for large scale development

The German biogas industry has grown into a specialized and integrated model that incorporates design, production, operation, service, equipment manufacturing and export. Big biogas projects are operated and managed by specialized and highly automated companies at low operating cost, thanks to Germany's pivotal focus on developing biogas projects. According to the EBA (European Biogas Association) reports, single biogas projects in Germany are shifting to larger scale development, despite the fact that EEGs in different amendments have granted more governmental subsidies to small biogas power plants compared with their larger counterparts.

In parallel, medium size biomethane solutions between 100 and 300 m^3/h biogas production are just coming up in Germany to locally cover the energy demand for renewable heat, electricity and vehicle fuel and realise nutrient circulation of organic residues and wastes. Just for this scale, biogas upgrading technologies were developed in the last years. Obviously, these plants contribute locally to sustainability development at slightly higher specific cost than in larger scale but the social and environmental benefits are of very high quality. Therefore, medium size biomethane solutions should not be neglected besides a focus on large scale solutions.

In an aim to catalyze this emerging new industry, China should deploy a strategy to industrialize biomethane sector nation-wide, strive for the economies of scale, and expedite engineering localization by enhancing system efficiency, establishing a business model for grid access and product sales. Moreover, to improve the equipment manufacturing system, advance technology development and lower the costs, more resources should to mobilized to set up a R&D platform.

Exit mechanism for incentive and subsidy policies

When it first drafted the EEG, Germany subsidized renewable energy's access to the grid with a fixed FiT. The subsidy exit mechanism should have been steadily growing fossil energy prices which exceed finally the cost of renewable energy production from biogas. Due to strong fluctuations of international energy prices this mechanism did not work but the industry grew bigger. In particular, when EEG-2000 and EEG-2009 were released, the industry wasn't ready in terms of technologies and business model maturity; however, large numbers of biogas power plants were still constructed. Given that the revision of subsidy policies lagged behind the industry development, subsidy hikes forced a huge financial burden onto the country.

From all countries with significant growth of the biomethane industry it is visible that reliable and continuous support like Feed-in-Tariffs e.g. for biomethane into the natural gas grid and priority gas grid access for biomethane plants are the main drivers for industrial development. This is visible for Germany, but at least for UK, France and Italy too.

When designing its own biomethane industry incentive and subsidy schemes, China needs to consider the incremental effect under the economies of scale. As the biomethane industry becomes more integrated and specialized, the market potential of organic fertilizer could be tapped to replace chemical fertilizers. Meanwhile, as technologies, facilities and system gradually improve, as well as operation costs continue to decline, China will have the conditions to form a market-based business model where companies are responsible for their own profits and losses. A sound exit mechanism should be established to mitigate any financial burdens on the state, and avoid a direct blow to the industry due to the "sudden exit of subsidy schemes".

The biomethane industry contributes significantly to greenhouse gas mitigation. Competitiveness with alternative energy supply chains on the long term will only be given when the value of greenhouse gas mitigation effects contributes to economy of biomethane projects. A sound exit mechanism keeping the biomethane industry alive should be escorted by a mechanism giving the greenhouse gas mitigation an economic value which could be paid by putting a financial burden on CO2 emittents.

Organic fertilizer production chain: an integral part for the marketization of biomethane industry

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12.2 Vision for the industry's development stages

Initial phase

Currently, the output of biomethane in China registers less than 100 million cubic meters every year, and there are only a handful of large-scale industrialized and commercialized projects within the industry. It is safe to conclude that the whole industry is still at its early stage within China. Based on its growth features, the industry's initial stage can be defined as one with an output under 3 billion cubic meters. To drive a rapid growth, state incentive policies and guidelines are needed to subsidize raw materials as well as consumer-end products. During this stage, strong stimulus policies would be necessary to attract large investments. Government shall help companies cut cost while encouraging them to streamline downstream industry sectors and establish product standards for the sake of biogas digestate and slurry-based organic fertilizers production. Meanwhile, supporting measures shall also be put in place to facilitate their product sales and increase their ROI (return on investment).

Booming phase

When the annual output of biomethane grows from 3 billion cubic meters to 10 billion cubic meters, it will be regarded as a booming phase which features fast growth rate. During this stage, industry policies shall transition accordingly from strong stimulus-driven policies to weak ones; a subsidy exit scheme should be set up; biomethane should be treated in the same way as other unconventional natural gas like shale gas and CBM (coalbed methane); and a quota system should be established at the right time to boost market consumption.

Mature phase

When annual output reaches more than 10 billion cubic meters, the biomethane industry growth will reach a stable state where sound and robust industry policies are rolled out, a mature business environment set up, and a "polluter pays" principle will be fully implemented. When drafting the state industry policies, government shall strike a balance between biomethane's social attributes and its commodity attributes, meaning that a compensation system for organic waste treatment at the front-end shall be set up, and a market-oriented approach be deployed for the consumer-end products (biomethane and organic fertilizers), thus creating a healthy and sustainable cycle for the industry. Meanwhile, innovation and market-oriented policies shall be prioritized to drive a high quality growth.

12.3 Policy suggestions for the initial stage

Early formulation of biomethane incentive and subsidy polices for the end-use consumption

The feed-in tariff scheme is at the center of all EEG Acts in Germany. The country's biogas industry is well and effectively regulated through a well-designed feed-in tariff scheme approved by the German legislators. The EEG-2004 ("subsidies for energy crops") and EEG-2009 ("more subsidies granted") gave an immediate boost to the industry's take-off. Per the EEG regulations, subsidies are offered to the end-use consumption. Therefore, project owners must make sure their projects are built with high quality and great reliability. Advanced technologies were subsequently adopted to ensure smooth and safe operation of their biogas plants.

Governments at all levels in China grant different degrees of subsidies to biogas projects, but the subsidy schemes are different from those in Germany. Under the Regulations on the Management of National Bond-financed Rural Biogas Projects, certain financial subsidies are provided for the construction of biogas projects, which played a positive role for filling the funding gap thereof and encouraging wider application of biogas technologies in rural China. Unfortunately, years of field experience shows that this front-end subsidy scheme could not ensure the quality of project construction, as well as its operation effectiveness, so much so that project owners feel no sense of urgency to build and operate the projects well, and some contractors even try to cut corners or exploit the subsidy loopholes. Given how the existing scheme is causing harm to the biogas industry sustainability, it is essential to introduce an incentive and subsidy scheme that is consumption-oriented and requiring efficient and continuous biogas production to boost the industry growth. For those projects, especially the biogas upgrading projects, efforts should be made to work out a system that subsidize the actual production quantities, as well as an evaluation mechanism regarding the effectiveness of stimulus policies and subsidization for biomethane products, digestate and slurry-based organic fertilizer and GHG mitigation. A solid basis for predictable economy of a biomethane production project for at least 10 years should be created. This will motivate project investors to build high-quality projects, hence bringing about a healthier industry growth.

Constant improvement of policies and regulations through effectiveness evaluation

Under different versions of the EEG, agencies of the Federal Government are obliged to evaluate German regulations and submit reports to the Bundestag regularly. For example, EEG-2004 stipulated that the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) shall submit an assessment report on the effectiveness of the law before December 31, 2007. In 2007, BMU submitted a report detailing the renewable energy market, power production costs, environmental impact assessment (EIA) since the roll-out of the Act and their policy recommendations. This has laid a solid foundation and provided scientific reference for the future drafting work of EEG-2008 and such assessment reports were worked out on regularly basis until today.

Though efforts were made by China's agriculture and energy agencies to gather massive quantities of data on renewable energy development each year, systematic evaluations on the policy effectiveness were still absent, hence the lack of evidence for policy and scheme readjustment. The Renewable Energy Law of the People's Republic of China does not expressly require that government agencies or departments should, on a regular basis, report to the legislature on how and how well the Law is implemented. Due to the lack of an evaluation and feedback mechanism, China's legislature cannot keep abreast of the latest development regarding renewable energy to make timely adjustment. As a result, policymakers cannot institute or launch corresponding policies without sufficient legislative support. Therefore, China urgently needs to establish an evaluation and feedback mechanism for the Renewable Energy Law so as to drive the industry forward.

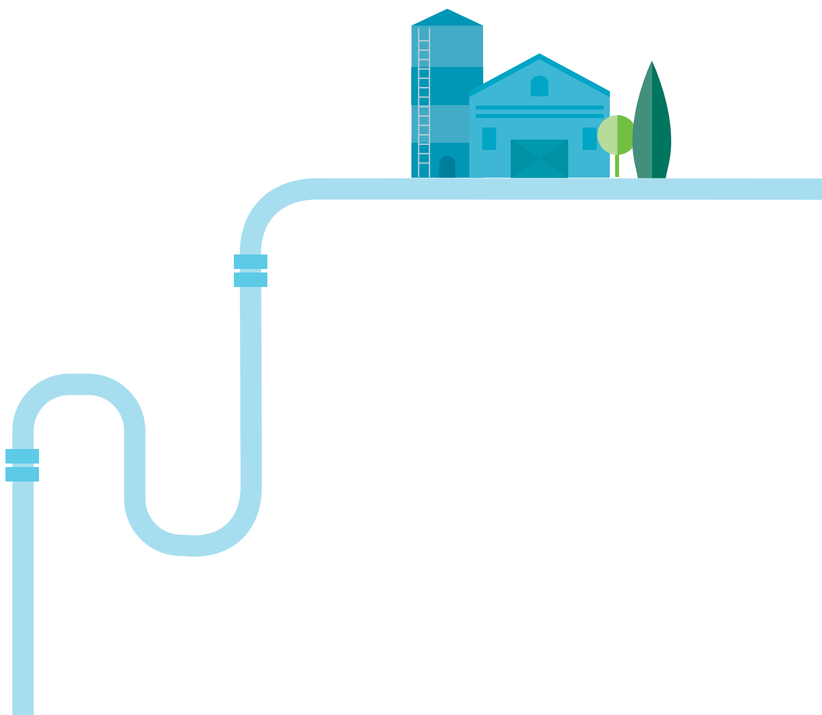
Expediting the set-up of a biomethane monitoring and diagnosis platform

In view of the problems arising from the biomethane project construction and operation, it is vital to set up an Internet-based project monitoring and diagnosis platform for China's biogas and biomethane industries. The platform shall be designed to provide technical support for biogas and biomethane exploitation, and offer professional services for corporate standards benchmarking and upgrading. Moreover, it should cover the whole industry chain -- from raw material input, production to output. Through the design and development of such a measurement monitoring platform that enables measurement monitoring, qualification & certification, operation supervision and data collection, China will have the baseline data it needs to formulate consumption subsidy schemes, as well as trustworthy information updates to facilitate the policy implementation.

Establishing an industry-wide supervision system

By incorporating internal supervision by businesses, and external supervision by industry platforms, third parties and government agencies, a four-in-one full-process supervision mechanism will be established, providing monitoring and supervision at all levels, in all dimensions and throughout all processes. This is the most cost-effective and efficient way for the government to carry out supervision. Such a system can guarantee effective supervision over the distribution of subsidies and support sustainable development of the whole industry.

Government supervision shall be led by state finance and energy agencies, which will guide and urge industry members to establish a self-regulation system, while third parties are employed to provide independent supervision on the industry. Biomethane companies shall set up a comprehensive mechanism that enables self-supervision over the complete process. Industry organizations shall develop an online supervision platform and database covering every single project. They shall also work with companies to collect and analyze their project information and data on a daily basis. Third-party independent watchdogs need to establish a subsidy and funding management system in order to provide supervision and evaluation services to industry platforms and projects. Their annual reports to the authorities and government agencies will serve as the basis for subsidy planning and granting.



Promoting marketization of the industry through flexible incentive and subsidy policies

The four amendments to EEG showcased a clear policy transition from a subsidy-drive model to a market-driven approach, as the primary challenge in the early stage was the doubts over project profitability and the lack of willingness to make investment in biogas power plants. EEG-2000 provided a legislative guarantee for the owners' interests, and therefore successfully stimulated the industry within Germany.

EEG-2004 and EEG-2009 both stipulated a higher baseline subsidy and wider range of additional subsidies for small biogas power plants, which effectively drove the mushrooming growth of many biogas power plants. Under EEG-2012, German government started to shift its policy focus towards integrating biogas electricity to the commercial grid; in contrast, EEG-2014 further weakened the favorable policies for the industry and encouraged a free market competition.

In its "Thirteenth Five-Year Plan for Renewable Energy Development", China proposed to commercialize and industrialize its biomethane products. Government agencies at different levels have made many attempts in this regard, but only yielded mixed results. Up to now, there are only a few successful biogas project operators within the country. Government agencies and departments shall give full consideration to the public benefits generated by the industry while setting up different marketization targets at different phases of its development: in the short term, intensive support should be given to biogas companies in order to incubate a cohort of industry leaders and cultivate the basic conditions for industrialization; in the medium term, supportive measures and subsidies shall gradually move to the back seat so that biogas product prices can be determined more by the market. This will also help the formation of a robust biogas industry chain with some of its segments directly exposed to market competition.

Building a R&D platform and an equipment supply system

After years of development, EU countries have achieved a high level of standardization in biomethane equipment manufacturing, technical processes, design and construction, intelligent operation and management, as well as products and services. As a result, a complete pro-industry system and a mature business model have taken shape. In light of the European experience, China shall develop its own biomethane R&D platform, and equipment supply system. Besides actively introducing and assimilating foreign technologies, China should develop a customized biomethane industry based on its own national conditions, in which companies shall play the leading role, assisted by research institutes and guided by industry organizations & agencies, in breaking major bottlenecks within the industry. As the industry develops, a technical and equipment R&D system will be established, covering anaerobic digestion, purification and upgrading, fertilizer production, and automatic control. Going forward, as the industry continues to develop, a group of recognized, high-level and well-reputed equipment manufacturers are expected to emerge from the market.

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