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renewable gas:
the sustainable energy solution

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Renewable Gas
- The Sustainable Energy Solution

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Summary

Renewable gases open up a new opportunity for gas companies and the gas sector as a whole. By greening the portfolio it can decrease the environmental footprint of the gas industry and also open new segments for gas companies. This is the main message of this report.

“Renewable gases” is the overall name for biogas (from anaerobic digestion), bio synthetic gas (from gasification) and biomethane (these gases processed to the specifications of natural gas).In order to be called renewable gas, the biomass should be renewable. Life cycle analysis (LCA) should be conducted to quantify the environmental footprint decrease and to ensure the sustainability of the renewable gas chain.

To produce renewable gases, many proven technologies are available and the production of biogas is growing fast in many countries. To explore the full potential of renewable gases, gasification of biomass should be further developed. Biogas and bio synthetic gas can be used directly on site or transported to specific users by a dedicated grid. Once processed to biomethane it can be fed into the natural gas grid and used as such. The best choice depends upon local circumstances, mainly governed by investment costs and economical incentives. In developed gas markets, currently the costs of producing renewable gases are higher than for natural gas. In emerging gas markets however, the direct use of biogas competes with the use of coal, briquettes or kerosene.

Feeding biogas in the natural gas grid is a new challenge for the grid operators as it requires a new way of thinking about balancing production and demand and of ensuring safety for the customers. Grid operators are therefore encouraged to develop smart gas grids and be involved in gas quality monitoring as well as in setting up specifications and standards to enable the use of the gas grid as the most energy efficient and environmentally friendly way to transmit renewable gases.

The sustainable development of renewable gases calls for the introduction of appropriate governmental policy and legislation and promotion of green gas as a contribution to mitigate climate change. In developing this framework, the gas industry should take a pro-active attitude and help increase public awareness. The production of renewable gases leads to the creation of local investments and business opportunities.

Renewable gases offer an opportunity for the gas industry to grow and green the business. It is the best step forward to provide society with a sustainable energy solution; clean, affordable, reliant, efficient and secure.

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1. Renewable gases and the gas industry

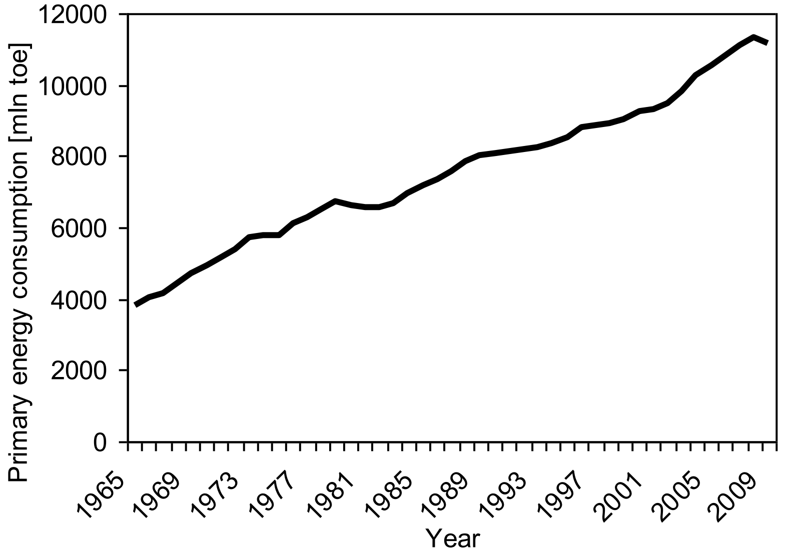
The energy market is fast changing. Natural gas, the cleanest of the fossil fuels, was once regarded as a commodity with a stable future and a clear playing field. But now the global situation has changed. Due to political choices and economical possibilities, the perception towards natural gas varies leading to a situation where in some countries natural gas is a welcome addition to the energy mix, whereas in other countries, there are attempts to stop using natural gas in parts of their markets.

A snapshot of the current situation at the energy markets gives us the following picture:

- continuous growth of energy consumption and increase in energy prices (see Figure **1** on the energy consumption for the past 25 years);
- depletion of existing energy resources reserves and growth of political contradictions between countries - energy exporters and countries dependent on energy import (Table 1 shows the predicted dependency of the EU on energy imports);
- continuing market liberalisation (energy consumers may choose suppliers);
- rise in market competition between energy and resource suppliers;
- Kyoto protocol and post Kyoto agreement, growth of public awareness towards the global environmental threats, strengthening the requirements for energy conservation;
- Intensification of life and business activities and search for new products (complex energy solutions) by energy market players.

The development of the energy markets has led to the emergence of several significant bottlenecks that may hinder their future growth. The introduction of green gas could provide the solution to some of the existing problems.

Figure 1: Energy consumption dynamics, 1965-2009



Source: BP statistical review of world energy 2010

Table 1: EU Forecasted Dependency on Energy Import

	1990	2000	2010	2020	2030
Coal [%]	17,5	30,8	46,1	49,5	59,0
Oil [%]	80,9	76,4	83,7	92,7	93,8
Natural gas [%]	47,5	49,6	62,8	81,4	84,6
Average [%]	47,7	47,2	55,0	63,5	64,9

Source: DENA (German Energy Agency)

From the point of view of the private companies, the green gas opens entry to a new segment in the global energy markets.

The Kyoto protocol and the so called '20/20/20' Directive of the European Commission have formed a new segment of the world energy market: the renewable energy segment. According to different estimations, by 2020 its volume in the European Union in gas terms will be up to 40 bln. m^3 of biomethane, which in itself represents quite a significant market.
For the moment, this market is still divided into small national markets in different countries, but it is clear that in future, it is transforming into a single European market. The possibility to operate on a bigger scale increases the attractiveness of biogas as a product for energy companies and private investors.

Table 2 summarises the possible role of renewable gas in some aspects of the energy supply. Both the existing and expected demand for renewables, extra margins and the opportunity to trade large volumes on one hand, and the positive impact on the current problems of the energy markets on the other, make renewable gas an attractive energy source that requires detailed analysis.

This report gives an overview of the possibilities to apply renewable gases. In chapter 3, the technological developments in production and distribution of renewable gases are summarised. Chapter 4 deals with legislative aspects and chapter 5 with economical aspects. Environmental and social aspects are presented in chapter 6. Finally, the potential of renewable gases and the prospective are presented (chapter 7) and recommendations for the gas industry are given (chapter 8).

Table 2: Green gas role in meeting existing expectations in the energy markets

Aspect	Current results with fossil fuels	Renewable gas role
Decrease in prices for final consumers	Continuing price increases in spite of slight decrease in gas consumption in Europe in the last 4 years	Currently does not allow, due to high cost of biogas production. May be possible in future with the technology development and increase in scale
Possibility to choose energy supplier	The acquisition of small and medium gas suppliers by large energy companies, resulting in oligopoly market	Allows, due to increase in number of gas suppliers (small and local or very specific on biogas)
Improvement of gas business transparency	Slight increase in transparency of the gas business for investors	Allows
Energy independence and guarantee of supply	Higher dependency from energy suppliers, increase in international competition for energy resources between countries	Allows, arising from having own gas producers (currently on a small scale level but with the technology development it may give a higher level of own gas production)
Increase in reliability and efficiency of work of the gas sector	Efficient technical approach from production to customers	Allows enlargement and improvement in the existing gas infrastructure
Improvement of ecology	Does not allow	Allows

2. Definitions

Renewable gases or gases from biological origin include methane- or hydrogen-based gases that can be produced by using different biomass fractions as raw materials and different technologies for fuel conversion. There are two main conversion technologies to produce methane-based gases: anaerobic digestion and gasification (see Figure 2). This section gives an overview of the definitions used in this report. Also some common definitions are summarised.

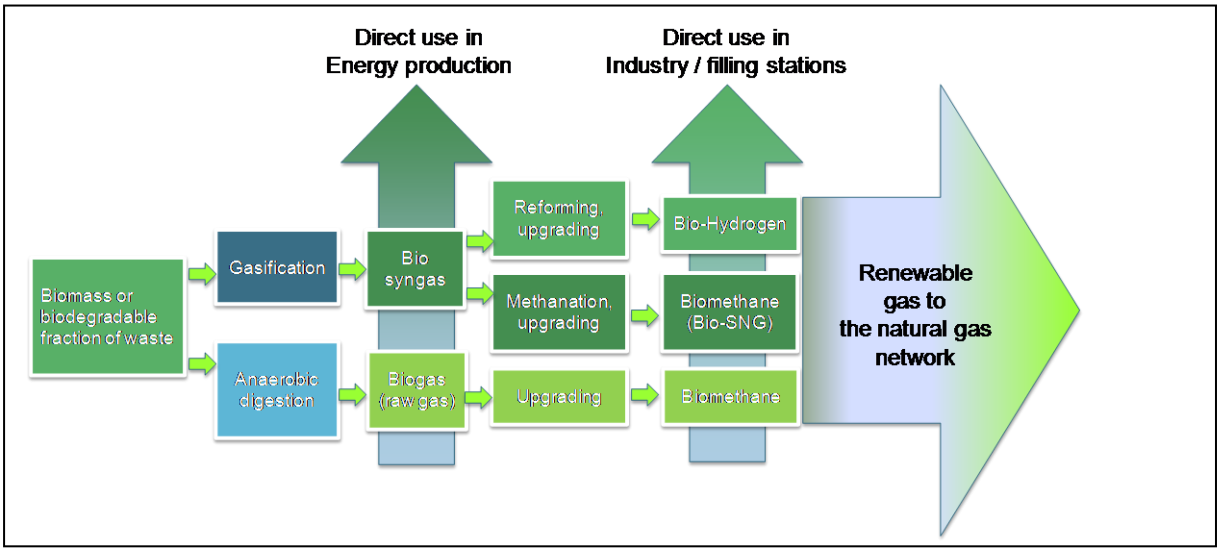
Biogas is the raw product of the biological process of anaerobic fermentation. Biogas is a mixture consisting basically of methane (CH_4) and carbon dioxide (CO_2). Typically biogas consists of 35-65% methane. The other components of biogas include carbon dioxide, water vapour, nitrogen compounds and trace species. Biogas can be used as such in energy production plants or dedicated processes.

Biomethane is biogas that has been purified to resemble natural gas (in terms of heating value, composition). It consists of 95-97% methane. Biomethane is considered suitable for many end-use applications and is considered suitable for inclusion in general pipeline systems, depending upon other characteristics of the gas and specific tariff requirements. Biomethane is also called **green gas** in the Netherlands or **renewable natural gas** in the United States. Biomethane can be used as a gaseous biofuel, in which case it is called **biomethane vehicle fuel**. It is used exactly like natural gas, and to supply a vehicle it must be compressed to 200 bar in a compression station. In its mandate M 475 issue to CEN, the European standards body, the EU aims at defining standards for biomethane as a vehicle fuel and for its injection into natural gas pipelines.

Bio syngas is the product of the thermal process of gasifying the biomass. It consists of a mixture of mainly hydrogen (H_2), carbon monoxide (CO), carbon dioxide (CO_2), water vapour (H_2O) and methane (CH_4). The composition of syngas varies depending on the gasification technology, gasification agent and operational conditions.

Bio-SNG (Bio-Synthetic Natural Gas) is bio syngas to which methanation is applied. The methane content which can be obtained by this process is at least 95%. This gas is suitable to inject into the natural gas grid.

Figure 2: Process of renewable gas production



Note that there are no universally applicable definitions for renewable gases in use but by technical terms biogas is defined as raw gas resulting from the anaerobic digestion of biomass (before upgrading) and biomethane as biogas upgraded to the pipeline quality. However, very often biogas and biomethane are considered as synonyms and the term ‘biogas’ is used for upgraded gas, too. Especially, companies active in gas business use biogas as a commercial or brand name for biomethane.

3. Technological developments and trends

3.1. Introduction

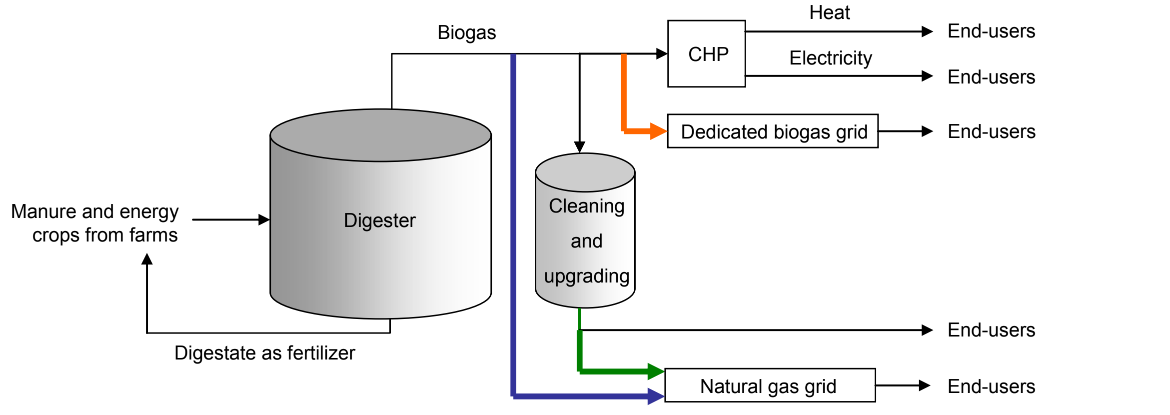
This section presents the technological aspects concerning renewable gas production and distribution. In the first two parts, the production methods, covering digestion and gasification are dealt with. The third and fourth part of this section deal with distribution and pricing of the gas. Finally, the possibilities to use biogas and biomethane are presented.

3.2. Digestion: aerobic and anaerobic

Anaerobic digestion is a bacterial process that is carried out in the absence of oxygen. The process can either be thermophilic digestion in which sludge is fermented in tanks at a temperature of 55°C or mesophilic, at a temperature of 30 to 40 °C. Thermophilic digestion is more expensive in terms of energy consumption for heating the sludge.
Anaerobic digestion generates biogas with a high proportion of methane. The methane generation is a key advantage of the anaerobic process. Its key disadvantage is the long time required for the process (up to 30 days) and the high capital cost. Figure 3 shows an overview of the production of gas by digestion. The three options of distribution are presented later in this report.

Aerobic digestion is a bacterial process occurring in the presence of oxygen. Under aerobic conditions, bacteria rapidly consume organic matter and convert it into carbon dioxide. Because the aerobic digestion occurs much faster than anaerobic digestion, the capital costs of aerobic digestion are lower. However, the operating costs are typically much higher for aerobic digestion because of energy costs for aeration needed to add oxygen to the process. For gas production aerobic digestion is not used.

Figure 3: Overview of the digestion process



Both the digester and the cleaning and upgrading can be either decentralized or centralized. Three options for distribution are shown (blue, orange and green lines). *Adopted from: Vol gas vooruit!*

3.2.1. Biomass sources:

The following sources are most common for the production of biogas.

- Sewage treatment plants: Sewage treatment plants produce methane rich gases.
- Landfills: All landfills produce methane rich gases. Collection and utilisation of the gases are quite well possible. Improved collection, processing and utilisation of landfill gases will be an important tool to increase the importance of landfill gas.
- Cleaning of organic industrial waste streams: Anaerobic digestion processes are often successfully applied to clean the waste streams of agricultural processing and food industries. The methane rich gases are mainly utilised to produce electricity.
- Grass and energy crops
- Algae
- Municipal organic waste: Compact installations convert municipal organic waste to methane rich gases at higher temperatures.
- Animal manure

3.2.2. Survey of production technologies

Centralised biogas plants

Animal manure, mostly slurry, is transported from farms to the biogas plant. Often, food processing industries and municipalities take care of the transportation of waste to the biogas plant. However, it is becoming more common that purpose grown energy crops are delivered by their producers directly to the biogas plant, usually chopped into pieces of a few centimetres in length.

In the biogas plant, manure, organic waste and, if appropriate, energy crops are mixed and digested in anaerobic tanks for 12 to 25 days. During this period effective sanitation takes place and weeds and pathogens are killed on a satisfactory scale. Often, the digestate is fermented in a second fermenter tank to solid fuel and liquid fertiliser. In Germany, there are a lot of these so called Nawaro (Nachwachsende Rohstoffe: regrowing base materials) reactors.

In order to increase production stability and capacity and to minimise power consumption, the following technical details are studied and developed further based on practical experience:

- Preference of thermophilic digestion depending on manure composition
- Addition of organic waste
- Buffer tanks for extracted slurry contributing to gas production
- Mixing and stirring equipment
- Pump design
- Heat exchangers between incoming and extracted slurry
- Removal of sand from mixing tanks and reactors
- Abatement of smell from the plants
- Cleaning of gas for hydrogen sulphide, ammonia, particulate and, if present, siloxanes.
- Water removal

Farm biogas plants

The biogas production on farms uses basically the same processes as centralised plants. However, the size and the setup of the digestion installation varies. The reactors include horizontal and vertical steel tanks as well as concrete basins. The mixing devices range from stirrer and propeller to pump.

Most plants have a gas storage facility to take advantage of power peak hours. The storage may be established as a gasbag covering the reactor or as a gasbag in a separate building.
In most cases, the farm establishes a CHP facility to convert the biogas into electricity and heat. The heat is usually distributed to the farm itself and to nearby users. The electricity is sold to the power grid and may partly be used by the farm. This depends on the tariff structure and the subsidy for grid injection that may be applicable. When the scale is large enough, the conversion to biomethane may be economically feasible.
Like the centralised plants, the smaller farm plants have found it attractive to mix manure and organic waste to stabilise and increase productivity. However, the requirement of heat treatment of waste at 70 °C for one hour for hygienisation of the biogas in some countries seems to be a blockage.

Sewage plants

The biogas technology has its origin in sewage plants where digestion of biomass is used since about 100 years ago. It results in a lower amount of dry content than can be obtained by oxygenation. The energy production through biogas was of minor importance to these plants although first injection of the produced biogas into the gas grid is reported as early as 1956 (sewage plant Mönchengladbach, Germany). Today the biogas energy production has attracted attention. The replacement of oxygenation by digestion has two effects: the energy for oxygenation is not needed anymore and the digestion produces energy.

Landfill

Landfill gas is produced biologically from organic material in waste deposits. The gas production peaks at about 1 year after landfill closure. Waste continues to produce landfill gas for as many as 20 or 30 years after being landfilled.
The most common method of LFG collection involves drilling vertical wells in the waste and connecting those wellheads to lateral piping that transports the gas to a collection header using a blower or vacuum induction system The extraction of the gas is seen not only as a source of energy, but also as a precaution against greenhouse gas emission to the atmosphere. An additional advantage is the reduction, often even elimination, of odour emissions. The occurrence of fires and explosions caused by involuntary methane emissions is significantly reduced by extracting LFG.

Macro and microalgae to biogas

Today, analyses are carried out on the technical potential of macro and microalgae for biomass production and greenhouse gas abatement, given their ability to use carbon dioxide and the possibility of them achieving higher productivities than land-based crops.
There are multiple claims in this sector but the use of algae as an energy production system is likely to have to be combined with waste water treatment or uptake of nutrients and minerals from polluted natural resources and co-production of high value products for an economical process to be achieved [5].

Dry biomass

Woody materials represent the principal resource for the production of biomethane through gasification. This resource fraction includes forest potentials, wood wastes, straw and purpose-grown short rotation coppice.
Thereby, wood wastes comprise industrial processing residues and high quality discarded wood only. The exclusion of too contaminated waste wood fractions such as part of construction and demolition wood and other is expressed by the utilisation rate. Dry biomass cannot be digested, but has to be treated thermally to produce gas.

3.2.3. Cleaning and upgrading techniques

Biogas compositions and boosters

Table 3 shows typical compositions of product gas for different processes

Table 3: Typical raw (untreated) biogas compositions at the different plants

Component	Digestion plant	Sewage plant	Landfill
Methane [%]	60 – 70	55 - 65	35 - 55
Carbon dioxide [%]	30 – 40	balance	30 - 40
Nitrogen [%]	< 1	< 1	5 - 15
Hydrogen sulphide [ppm]	10 – 2000	10 - 40	50 - 300

The production rate of biogas can be increased by additives or boosters. The optimum conditions are often defined by the CNPS-ratio which for methanogene organisms is given as 600:15:5:3 (C = Carbon, N = Nitrogen, P = Phosphor, S = Sulphur). These boosters may promote the degradation and subsequent fermentation of substances such as grass or fibres. Excessive use of boosters may lead to acidification of the digestate and to a varying gas composition.

Desulphurisation

Because sulphur components are corrosive, the sulphur should be removed from the gas stream. When desulphurising biogas, one has to distinguish between bulk removal and fine removal.

For biogases with high contents of hydrogen sulphide (typically 1000 to 2000 ppm) a first bulk desulphurisation step is applied to reduce the sulphur content to 20-50 ppm
For removal down to 5 ppm hydrogen sulphide or lower, impregnated active coal is commonly used. Since oxygen is consumed in the reaction, the presence of a small amount of oxygen (about 1000 ppm) is necessary to get sufficient loading of sulphur to the active coal.

Carbon dioxide removal

The most important step in the upgrading of biogas to natural gas quality is the removal of carbon dioxide. One important criterion for a carbon dioxide removal technique is the methane slippage (the loss of methane during upgrading). Local or national regulations may set limits for the maximum allowable loss of methane.

By now the following techniques are commonly used.

- ***Pressure Swing Adsorption***

  Pressure Swing Adsorption (PSA) purifies gas streams by means of adsorption of impurities on active coal or zeolites.

- ***Physical absorption***

  Water or another liquid such as alcohol can be used to bind carbon dioxide. When water is used, this is called water scrubbing or pressurised water wash (PWW).

- ***Chemical absorption***

  Chemical absorption is comparable to physical absorption. A liquid such as amine is chemically bonded to the carbon dioxide. In order to recycle the solution, a heat treatment has to be applied.

- ***Membrane separation***

  By means of semi-permeable membranes, methane can be separated from carbon dioxide. The driving force can be a pressure difference, a concentration gradient or an electrical potential difference.

- ***Cryogenic separation***

  By cooling down the gas, trace gases and carbon dioxide are removed in various temperature steps. The remaining methane can be cooled down to liquid biogas (LBG).

Comparison between various upgrading techniques

In the table the main characteristics and advantages and drawbacks of the upgrading techniques are summarised:

Table 4: Summary of the performance of several CO_2 separation techniques

	PSA	PWW	Physical absorption	Chemical absorption	Membranes	Cryogene
Robustness	++	+	-	- -	++	- -
Gas quality [%]	>97	>97	>98	>98	<90	92-9
Ease of operation	+	+	O	-	++	- -
Experiences	++	++	O	O	-	- -
Environmental effects after breakdown	+	O	-	- -	+	+
Energy consumption [kWh/Nm^3]	0,20 - 0,25	0,20 - 0,30	0,22 - 0,29	0,60-0,75	0,06 -0,50	0,40- 0,95
Resistance to quality variations	++	++	++	++	++	- -
Waste removal	++	+	O	O	++	+
Maintenance	++	+	+	+	++	+
Space requirement	++	++	O	O	++	O
Working pressure [bars]	2,5-10 and vacuum	>10	2,5-10	1-3	>1 and vacuum	25-80
Methane loss [%]	<3	<2	<1	<<1	>>10	<2

++ very favourable, + favourable, O average - unfavourable - - very unfavourable

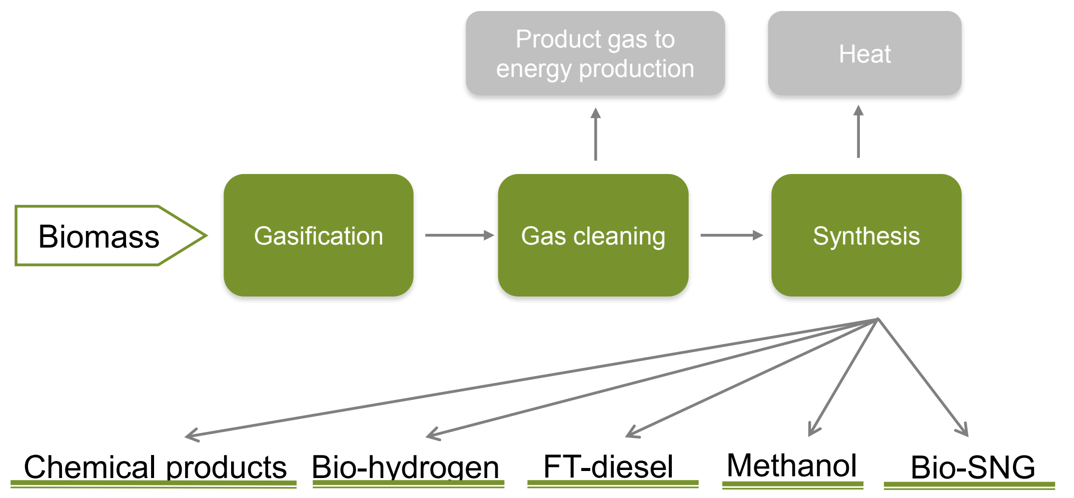
Water removal

Any water shall be removed to avoid corrosion by the water itself or by corrosive acidic solutions formed by dissolving of hydrogen sulphide or other contaminants. Moisture in the pipelines could also lead to accumulation of condensate or, when stored under elevated pressures, to condensation or freezing.
Water can be removed by cooling, compression, absorption or adsorption.

3.3. Gasification technology for syngas production from biomass

Besides digestion, renewable gases can also be produced by thermo-chemical processes (gasification). When biomass is gasified, syngas or synthesis gas is produced. Syngas contains among others carbon monoxide, carbon dioxide, hydrogen and methane. The product gas is cleaned and via different synthesis processes different final products can be produced. In the case of the synthesis process is methanation, the final product is called SNG (synthetic natural gas or substitute natural gas) or bio-SNG. Instead, by reformation processes, bio-hydrogen can be produced. Similar to Fischer–Tropsch synthesis, liquid FT-diesel can be produced. Therefore, bio-SNG and bio-hydrogen are potential final products of biorefinery. Figure 4 shows the process scheme to obtain chemicals and several fuels from biomass.

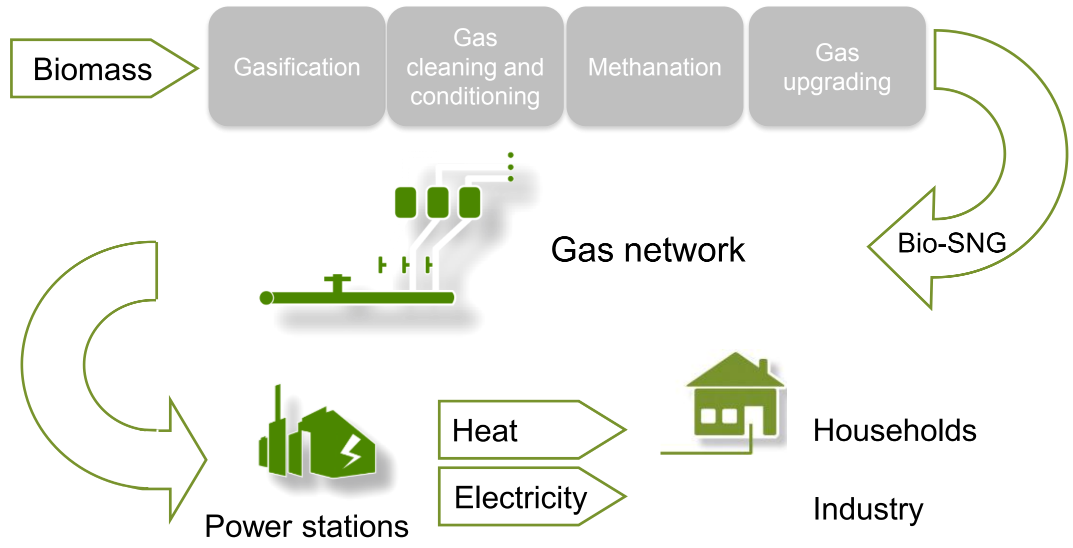
Figure 4: Production of renewable fuels and chemicals from biomass



Source: Gasum

Similar to natural gas, biomethane can be compressed to a pressure up to 200 bar and it can be used as a transportation fuel. In Sweden and the Netherlands compressed biomethane is called compressed biogas (CBG).

Figure 5: Overview of the gasification process



Source: Gasum

Figure 5 shows the production process of bio-SNG. In the first stage, the dried biomass is gasified in the gasifier using oxygen or/and steam as a gasification agent. After gas cleaning and conditioning, the methane content of syngas is increased in the methanation synthesis. After the gas is upgraded to the same quality as natural gas in the grid. Bio-SNG distributed via gas network can be used in all the same applications as natural gas, such as combined heat and power (CHP) plants, industry and greenhouses. It is particularly suitable for distribution for use as a transport fuel via the natural gas filling station network.

3.3.1. History and current practices

The idea to gasify wood and produce bio-based SNG goes back to the beginning of the 1990s. The Energy Research Centre of the Netherlands (ECN) has studied the production of bio-SNG (green gas) from the beginning of the millennium. In Switzerland, the Paul Scherrer Institute (PSI) started research into this technology in 2002. In addition, technologies employed in the production of bio-SNG have been studied and developed actively in Austria and Sweden (Chalmers). In Güssing, Austria, there is a pilot facility of 1 MW in operation. In Finland, VTT has studied biomass gasification in co-operation with industry since the 1980s and compared bio-SNG production with the other alternative applications of biosyngas [14, 16, 17].

Göteborg Energi and E.ON have a project called GoBiGas (Gothenburg Biomass Gasification Project) where bio-SNG will be produced through thermal gasification of forest residues. In the first phase of the project, the output of bio-SNG will be 20 MW and in the second phase 80 MW. The first phase is under construction at the moment and it is expected to be in operation in late 2012 (Göteborg Energi, 2011). E.ON's goal is to build SNG plants with a capacity of 200 MW. Gasum, Helsingin Energia and Metsä-Botnia are planning a biorefinery of 200 MW for bio-SNG production in Joutseno, south-eastern Finland.

3.3.2. Characteristic properties

In bio-SNG production, an energy yield of 65−70% from wood to bio-SNG can be achieved [15, 23]. The yield can be improved by increasing the methane content in the synthesis gas after gasification, which reduces the need for methanation and heat removal from the process in the methanation stage. If there is a need for the heat produced in the methanation stage, the overall energy efficiency of the process can be up to 80−90%. In the GoBiGas project, the objective is to reach a yield of 65% and an overall energy efficiency of over 90% [13].

As a fuel bio-SNG has all the excellent properties of natural gas, such as high energy-efficiency and clean combustion: combustion of bio-SNG does not produce sulphur dioxide, particle or heavy metal emissions. Bio-SNG also has additional benefits. Biorefineries producing bio-SNG enable highly effective utilisation of biomass energy content in all stages of the fuel cycle: high yield in the production stage, energy-efficient transmission in the gas network and high efficiency in gas utilisation. Because renewable biomass is used as a raw material in bio-SNG production, it is a carbon neutral fuel. In addition, during the methanation process, the biomass-based CO_2 can be captured, which would make the CO_2 emissions of bio-SNG negative.

3.3.3. Gasifiers for syngas production

The technology for the thermal gasification of biomass is mainly derived from the gasification of coal. There is a tremendous worldwide experience on the gasification of coal [12]. The coal gasification is a mature technology, able to fulfil any rational commercial requirements. The current coal gasification technology has three branches to be distinguished by their reactor characteristics: fixed bed, fluidised bed and entrained flow gasifiers. These branches are also commonly used for biomass gasification.

Besides air, the reactant gases can be oxygen, steam and hydrogen. Air is available at the lowest cost but the resulting gas will always contain a large amount of nitrogen. The use of oxygen will result in a richer product gas and allows the use of a more compact gasifier and syngas treatment system. Adding steam to the gasification process will result in additional hydrolysis processes. Water is available at low cost. The resulting hydrolysis improves the quality of the product gases. Also the addition of hydrogen will result in a better product gas, but is only feasible in the scarce situation where hydrogen is available at low cost and not usable in other, more profitable, applications.

Another differentiation is the process conditions given by the temperature and the pressure inside the reactor. Higher pressure and temperatures will result in more compact reactors. Higher pressures (typically 30 - 50 bar) will also result in a larger fraction of methane and some other hydrocarbons in the syngas. Higher temperatures (typically 1200 - 1600 °C) will result in higher hydrogen and carbon monoxide fractions in the syngas. Rising pressure and temperature in biomass gasification plants will lead to increased costs for the reactor and auxiliary equipment.

Dedicated designed biomass plants use atmospheric or moderate (3 - 5 bar) pressure. Also moderate gasification temperatures (400 - 800 °C) prevail.

3.3.4. Technologies for syngas cleaning, methanation and upgrading

The gas generated from coal has different applications. They include distribution to consumers, the generation of power, the conversion to pipeline quality gas (methanation) and the conversion to a nearly infinite range of chemical products. All these mature processes are available for the upgrading of syngas from biomass.

The product gas of gasification, also called syngas, contains mainly hydrogen (H_2), carbon monoxide (CO), carbon dioxide (CO_2), water vapour (H_2O) and methane (CH_4). The composition of syngas varies depending on the gasification technology, gasification agent and operational conditions.

Methanation is a catalytic process where syngas of gasification is converted to methane using nickel-based catalysts. Syngas contains impurities such as sulphur and chlorine compounds that have to be removed before methanation because they weaken the activity of methanation catalysts. In case of biomass, tars are a bigger problem than in coal gasification. Therefore, gas cleaning is more challenging for biomass-based syngas than for coal-based syngas. In addition to gas cleaning, synthesis gas has to be conditioned to make its gas composition favourable for methanation.

By methanation, the gas is upgraded to at least a methane content of 95% by removing CO_2, water vapour and other impurities from the gas. Before feeding bio-SNG into the natural gas transmission network, its pressure is increased to the pressure of the gas network.

3.4. Transport and distribution

3.4.1. Three basic options

When considering transport and distribution of biogas there are three basic options (see Figure 3):

1. Upgrade the biogas to biomethane and feed it into the natural gas grid (green line).
2. Feed the biogas into the natural gas grid (blue line)
3. Use a dedicated grid for the biogas (orange line);

In this chapter the three options will be discussed, starting with upgrading to biomethane and feeding this into the natural gas grid.

3.4.2. Upgrading to biomethane and feeding into the natural gas grid

Upgrading biogas to biomethane and feeding it into the existing natural gas grid is a logical option. Logical, because by choosing this option, the consumers will observe no changes at all, since by definition the biomethane should have the same properties as the natural gas it is replacing. Full benefit is made of the existing grid and existing demand.

The following paragraphs will go into more detail into the aspects that are related to feeding biomethane in the transport- or distribution grid.

Gas composition and the grid operators' responsibility

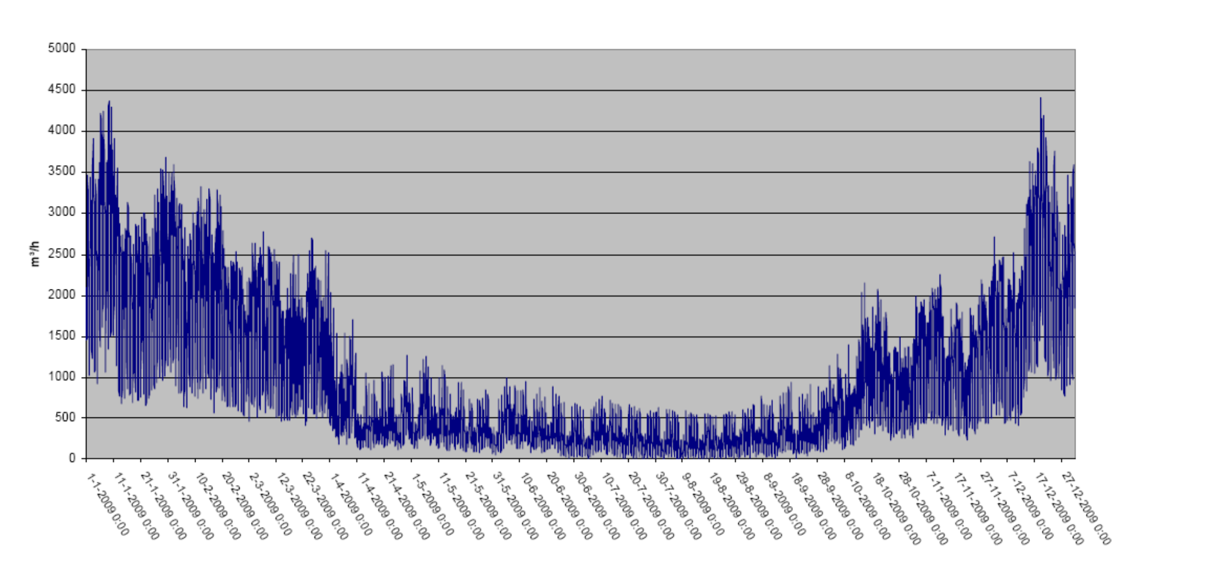
In the conventional setting, the well-known natural gas suppliers provide gas within well defined specifications. They make sure that the gas they deliver to the transportation and distribution grids complies with all relevant regulations and specifications. For grid operators, this is seldom considered a big issue, since we all rely on the professionalism of these large supply companies. Verification of the gas compliance is generally conducted on all major entry points of their gas networks. It is completely clear who delivers the gas that is distributed, so even if there is an issue with the quality, there is no argument on the responsible party. These well-known suppliers have the financial power to bear this risk.

In the biomethane setting, the same line of thought is valid. Delivering biomethane of the correct composition is the responsibility of the producer. He has to control his production technique and often also upgrading technique in such a way that the biomethane he wants to feed into the natural gas grid, complies with the relevant regulations and specifications. However, those regulations may also stipulate that the biogas producer is entirely in charge of production and treatment (clean-up) of the biogas, whilst the grid operator is in charge of adapting the biogas to the quality and energy content of the natural gas present in the pipeline, i.e. the conditioning of the cleaned biogas to pipeline conditions. The reason is that in a number of cases the cleaned biogas will not be able to reach the calorific value of the natural gas that contains higher hydrocarbons whereas biomethane features only one hydrocarbon: methane. Such regulations do exist, imposed by states ordinances, for example in Germany and Switzerland.
However, even where the entire process is left to the biogas producer, these being often new players and usually relatively small companies compared to the natural gas suppliers, the grid operators feel the need for additional supervision.
The consequences of odd composition or even of harmful substances for both their own assets as well as the assets and safety of the customers are of major concern. Besides, if negative effects are found, the cause or the originator is not as obvious as it is in the conventional situation.
This leads to a change in the line of thought where the grid operator takes a more active role in monitoring the gas composition. After all, when several suppliers and producers feed natural gas and biomethane into the grid, there is only one party where all the information comes together.

Pattern of usage

The typical pattern of demand in a gas grid follows a yearly cycle and a daily cycle. The daily cycle shows two peaks in the morning and the evening, and a low demand during the night. The yearly cycle shows higher use in winter time and lower use in summer time (see Figure 6). The difference between the peak demand and the lowest demand is enormous. Summer nights with no demand at all are not exceptional.

Figure 6: Typical example of the yearly pattern of gas usage (8 bar grid)



A typical biomethane producer however, prefers a stable, continuous flow. This difference in production and demand may lead to a situation where the production flow during the summer cannot be handled. This effect becomes more acute if more biomethane producers want to feed into the same grid and this will hinder efforts of ”greening” our energy system when individual producers have to limit their production because of demand issues.
Therefore, instead of limiting the production of biomethane, it is preferred that grid operators and producers collectively work out technical solutions for this. One might think of local storages or the use of the storage capacity in the gas grid (dynamic pressures). A second option is to add extra interconnections to other parts of the gas grid (at the same pressure level or even upstream) to increase the distribution to areas where the produced biomethane can be used. A third option is to convert the biomethane to electricity and heat and to deliver this to the users. The best solution depends upon the local circumstances and regulations.

3.4.3. Location choices for interaction with the natural gas grid

The conventional gas grid has been designed to deliver gas from one or few points of ‘infinite’ gas supply, to all kind of customers on many different locations. As long as the pressure at the supply point is high enough, the gas will find its way to the customers through a maze of pipes from high pressures and large diameters down to low pressures and small diameters. The flow of the gas is driven by the demand of the customers only.
When producers want to feed in biomethane, they are usually not aware of this build-up of the gas grid. The location they choose for building the production plant is based upon the infrastructure above the ground, not the infrastructure below the ground. This can result in a conflicting infrastructural situation.

For instance, when a farmer wants to feed in biomethane directly from his own farm location, the farm will most likely be connected to a low-pressure, small diameter natural gas pipe. Because he is located in a low-populated area, there was never the need for higher pressure or larger diameter pipe. Moreover, the demand in this area will be very low, maybe even zero, during the summer nights. Therefore, to enable him to maintain a constant production rate, the existing natural gas grid has to be modified to make it possible to distribute the biomethane to a sufficient amount of customers. This modification takes time and money. It is up to the regional or national regulations to decide who has to pay for these modifications.
Therefore, in general, for new biogas plants designed with the option to feed into the natural gas grid a location which is close to industrial areas or cities is to be preferred.

3.4.4. Feeding the biogas into the natural gas grid

Although upgrading biogas to biomethane before feeding it into the natural gas grid is a logical option, one might also consider to transport and distribute biogas through the natural gas grid without or with only partially upgrading it to natural gas quality first. This is only possible without further consequences when the flow of biogas is small enough compared to the flow of natural gas for the mixture to be still within natural gas specifications. In practice, this means feeding in into high pressure transportation pipelines.

In each natural gas grid there are strictly defined natural gas specifications, describing minimum and maximum quantities of components and overall characteristics such as density and Wobbe index. If even after adding biogas to the flow of natural gas, these specifications are still met, then feed-in of the biogas is possible. This always needs close cooperation with the gas transporting company responsible for the gas quality in that pipe. The natural gas shall be "far" enough from the specification limit to allow for dilution of the biogas and still be within specification.

The main two advantages of this option are that there is always sufficient demand, meaning that the biogas producer has a very stable turnover, and that there is always back-up if the biogas producer fails to produce.

Financially, it has the advantage that there is no need for upgrading, however, since this is an option which is typical for high pressure transportation pipelines, compressing the biogas to higher pressures (e.g. 40 bar), will be necessary. Also there may be limitations on the possible locations because of the necessity for connection to a high pressure pipeline.

The second option for feeding in biogas into the natural gas grid, is accepting that the flow of biogas is relatively high compared to the flow of natural gas. In this case, the gas composition will vary in time because of variation in production and consumption rates. This is only possible if the appliances are capable of handling these varying compositions.

Financially, this is the optimal solution for society. There is no need for upgrading to biomethane, there is no need for compression to high pressures and there is always back-up by natural gas. Appliances that can handle varying gas compositions could be available at minimal additional costs. The complexity is the pricing of the distributed gas, a question which is comparable to the question for a dedicated biogas grid with more than one producer.

3.4.5. Distributing biogas through a dedicated grid

When using a dedicated gas grid for the biogas, there is no interference with existing natural gas grids. The advantage is that within such a biogas grid, all rules and contracts can be tailor-made to the producers and consumers on that grid. If a consumer, or group of consumers, is satisfied with the specific properties of the biogas of the producer(s), they can use it as their standard and adjust their appliances to these specific properties.

The grid operator can take these properties into account and operate his grid in a way that is specifically arranged for biogas. He can use specific piping material or specific working instructions and he can value his services at different costs than for a natural gas grid.

There is no need for expensive upgrading to biomethane.

There are however also disadvantages. Because such a dedicated grid will most likely be a new grid, the investments in the grid will be higher.

Not only will the producers and consumers need to be connected to each other by pipes, they also will need to have a similar planning as to when they start producing and consuming the biogas. And they will need to find a way to valorise the produced and consumed biogas, which may be complicated when there are producers with varying gas compositions connected to this grid.

The production and consumption need to be in line with each other, or else a connection to the 'outer world', the natural gas grid, may be necessary to provide back-up for insufficient production. Excess of production could be upgraded to natural gas quality, or the excess biogas could be used for producing electricity and heat in a CHP plant. Storing biogas, although technically possible, is a very costly solution, so storing is more an operational solution for matching short term mismatch between production and demand.

3.5. Custody transfer

Somewhere between biogas production and utilisation there are a number of custody transfers of the gas involved, and the two items connected with financial transfer are energy content and gas volume transported, which ,in principal, is no different from the natural gas system. Whilst the custody transfer from the grid to the final consumer is identical to natural gas, the custody transfer from the biogas producer to the grid operator, if different, is far more interesting. The legal metrology laws valid for the location will apply. For the determination of the value of the gas, the two items to be measured are

- The volume of the biomethane;
- Its energy content.

As biomethane, i.e. cleaned biogas, consists from usually 95 % up to 99.5 % methane, the same gas volume measurement techniques can be applied as for natural gas under those pressure, temperature and flow conditions as for example turbine meters, ultrasonic meters or whatever legal metrology allows at that location. Also, if metering happens after conditioning, the natural gas conditions apply, the gas resulting from the conditioning having properties very similar to those of the natural gas in the pipeline. However, in most cases it will be necessary to know the exact amount of biomethane injected because in many countries biomethane is enjoying different billing conditions as natural gas, such as direct subsidy or preferential tax regime.

The energy content can, under most legal conditions, be determined either by direct measurement in a calorimeter or by determination of the composition of the gas, followed by an applicable calculation equation (for example AGA 8, GERG 88, ISO 6976). Commonly, process gas chromatographs (PGC) are employed. However, the investment costs for such PGCs with acknowledgements of the metrology authorities are relatively high and are often the reason to exclude small biogas producing plants from grid injection.

As a rule of thumb, in Germany with its rather favourable legal framework for biomethane injection biogas plants with a biomethane production of less than 250 m^3/h are rarely worth connecting to the grid.

3.6. Utilization

This paragraph describes three cases of utilizing biogas, from simple direct use of biogas without any purification or partially upgraded biogas for CHP uses to the advanced purification of biogas making biomethane for NGVs, with or without injection into the natural gas grid[1].

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[1] REFERENCES:

1. Bio-Carbon Opportunities in Eastern & South Africa, issued by UNEP 2009
2. Report NO61, Niigata university agriculture dept, 2009
3. IGU WOC5 TF 1 Power point presentation
4. URL http://www.city.kobe.lg.jp
5. URL http://www.yanmar.co.jp
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7. URL http://www.hirakawag.co.jp/product/pro_katstarjsn.html

3.6.1. Direct utilization of raw biogas

- The first case is about direct utilization of raw biogas. Biogas direct utilization at small domestic houses has been rapidly expanding in developing countries in Africa and Southeast Asia such as Nigeria, Tanzania, India, China etc. In particular, small farmers in China and India are generating biogas by utilizing the manure of their livestock, human excrements and garbage.
- These farmers have installed biogas fermenter tank in their yards and connected the gas supply pipe to the in-house pipe to use the biogas as a fuel for cookers and boilers in the kitchen and gas lamps in the living room. According to recent research and studies, about 20 million houses have begun to use biogas in the last 15 years and the volume of biogas generated amounts to over 60 billion cubic meters. Average capacity of digesters are 5-10 m^3 and gas yield is around 300-600 m^3/year. Total investment which includes the cost for digester, gas piping and equipment such as gas cooker and gas lamps amounts to about 60,000 US dollars. On the other hand, by introducing biogas to their houses, they can save up to 50-90% of the annual cost for the coal, briquettes and kerosene and with the 18.000 US dollars subsidy by the Chinese government, it makes it possible to recover the initial cost within 1 to 2 years.

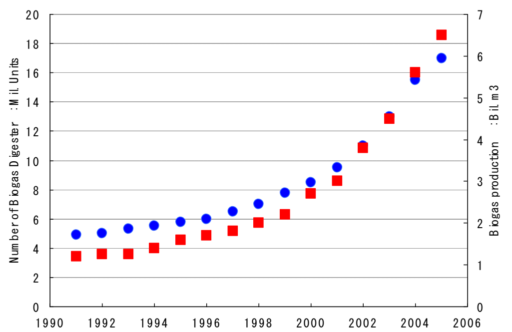


Figure 1: Direct biogas utilization

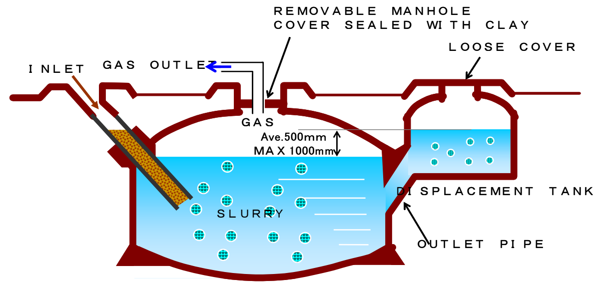


Figure 2: Biogas digester

- The study shows that gas cookers using biogas are much more energy efficient than coal or briquettes and also confirms that the number of CO poisoning accidents has been dramatically decreased.

Figure 3: Biogas digester

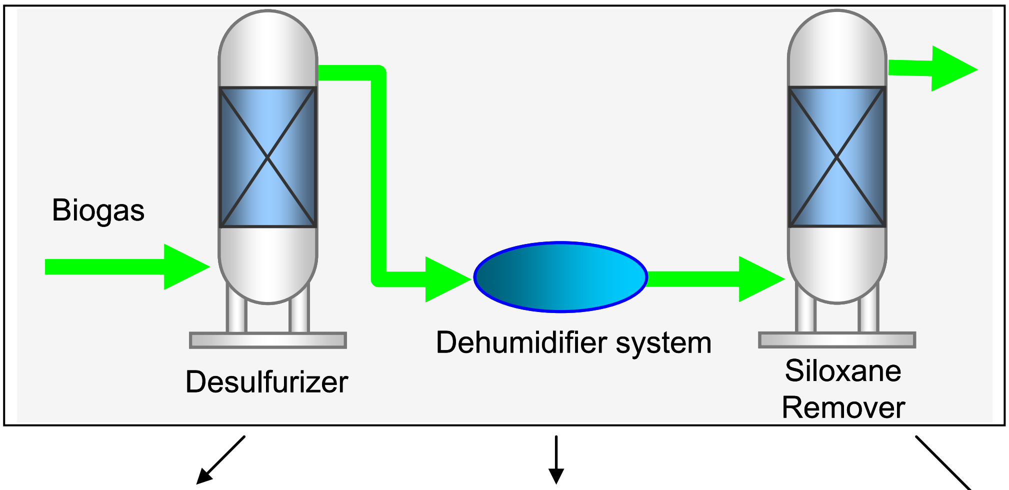
Figure 4: Biogas light

Figure 5: Biogas cooker

- The characteristic of the said biogas is as follows; gas calorific value is about 20 to 25 MJ/m[3] and contains 30-40% of CO_2, some percentage of Nitrogen, saturated moisture and 200-2000 ppm H_2S. The component of this raw biogas, gas yield and gas pressure tend to fluctuate by manure source and the outside temperature and these incidents sometimes trigger misfire of cookers and gas lamps burn outs
- These hazards coming from quality variations and high H_2S concentrations mean that direct utilization of raw biogas before purification or simple upgrading is not recommended in open appliances.

3.6.2. Utilization of biogas partially purified and up-graded onsite

The second case is utilization of biogas simply purified and upgraded at the generation site.
In developed gas markets, anaerobic fermentation process has been adopted at the factories for such as sewage sludge treatment, garbage treatment and food processing e.g. breweries and confectionaries in order to reduce their sludge, garbage, industrial waste and also to produce energy. Farmers in these developed gas markets have also started to utilize biogas as a fuel for generating electricity and heat.
In these cases, raw biogas is purified or upgraded to a certain level having gas components of 60-80% methane and 20-40% CO_2 so that it can be used for CHP systems or boilers.
In this case, biogas can be used after removal of hydrogen sulphide, moisture and siloxane through simple purification methods. By applying this biogas to any CHP system or boiler used onsite, the energy loss can be reduced considerably.
Compared to other biomass energy, biogas is evaluated as one of the most efficient biomass energy from the LCA aspect due to its low removal cost and high its energy efficiency.




Desulfurizer


Dehumidifier


Siloxane remover

Dedicated gas-engine CHP system and gas boiler have very high efficiency and reliability for fluctuated biogas. In some EU countries such as Germany, U.K, and The Netherlands considerable amounts of subsidy or special bonuses are provided from the government to the facilities where biogas is used for power generation.

25kW Biogas engine

1000kW Biogas engine

Biogas boiler

3.6.3. Utilization of biogas upgraded to bio-methane

The third case is about the utilization of bio-methane for NGVs or for injection into the utility gas pipelines. This bio-methane is produced from biogas through advanced purification. In many cases, biogas generated at the gas production site such as garbage treatment plants, sewage sludge treatment plants, and dairy and livestock farms cannot be entirely consumed on site. These biogas are refined further into bio-methane to be used directly in NGVs or injected into the natural gas grids. In this process, biogas is highly purified and odorized in order to reach the natural gas specifications quality:

- impurities such as H_2S, Siloxane, and moisture almost completely removed or at least abated at natural gas specification;
- CO_2, O_2, and N_2 are also removed, it may require calorific value adjustment by adding LPG to meet the gas utility’s standard. There are countries that do not request this kind of calorific value adjustment nor odorisation.

Items	Unit	Crude biogas	Ex. of crude biogas	Standard for CHP	Standard for NGV [3])	Ex. of bio-methane for NGV [3])	Standard for grid injection [4])
CH4	Vol%	58-80	59,7	58-80	≥ 97	98,2	-
CO2	Vol%	15-40	37,0	15-40	-	0,6	≤ 0,5
O2	Vol%	0,5-2,0	0,4	0,5-2,0	≤ 4	0,2	≤ 0,01
N2	Vol%	05,-2,0	0,8	0,5-2,0	≤ 1,0	1,0	≤ 1,0
H2S	PPM	200-3000	330	10-100 [2])	≤ 0,1	< 0,1	≤ 1,0
Siloxane [1])	mg/Nm 3	14,53	14,53	≤ 1	≤ 1	≤ 0,005	0
Heat value (HHV)	MJ/Nm3	21-32	23	22-32	39	39,3	45
Dew point	C	0-30	0 ≤	0 ≤	≤ -56	< -60	≤ -60
Odorant intensity	-	-	-	-	≥ 2000	3000	≥ 2000
Conc. odorant	mg/Nm 3	-	-	-	-		12-16

[1]) Siloxane: Organic silicon compound contained in the shampoo and hair conditioner. Siloxane is included in the biogas of sewage origin

[2]) The limit of the concentration of H2S depends on the CHP manufacturer

[3]) This standard is set by Kobe city

[4]) This standard is set by Osaka gas

Figure 6: Biogas NGV Station

Figure 7 Purification equipment

3.6.4. Conclusion

In order to utilize biogas in a most effective way and assure safety, it is essential to tailor the biogas by purifying it to suit the standards required by the purpose and situation of the user.
The most cost-effective way of using biogas is local consumption at the gas generation site, if possible. Most of the places, however, are not capable of consuming all the gas generated there.
The next option is to use biogas directly onsite as a fuel for NGVs. But in many cases, it cannot be a practical option due to the lack of sufficient NGVs to make the system economically viable.
Another possibility is to inject biogas into utility pipeline. In this case, biogas is required to be upgraded to bio-methane through a more advanced purification to meet the standards of the natural gas supplied by the utility as well as fulfilling the requirements of odorisation and calorific value adjustment.

In any of the cases above, achieving the effective biogas utilization requires gas purification most suitable to the situation and purpose of the biogas application.

4. Legislation and rules

4.1. Introduction

Biogas production is becoming more and more attractive, thanks to the gradual introduction of regulatory restrictions on the treatment of organic waste and several renewable energy commitments made by a lot of countries all over the world. Legislation and policies covering agricultural, environmental and energy aspects have an impact on the development and implementation of the production of biogas. Governments at all levels had to develop and implement well formulated long-term policies and favourable regulatory frameworks, coupled with appropriate incentives, which work to remove uncertainty in the market and set to attract increased investment in renewable energy technologies.

4.2. Situation in Europe

Among European countries, there is a general strong political tendency towards supporting renewable energy, especially after the Kyoto agreement. The European regulation framework sets a series of demanding climate and energy targets to be met by 2020, which consist on cutting greenhouse gas emissions of at least 20% below 1990 levels, reducing energy consumption by 20% through increased energy efficiency and meeting 20% of energy needs from renewable sources.

Biogas production is a promising and efficient way to satisfy all the European Union policies expectations. First, it provides the answer to the main objective of **the Renewable Energy Directive (2009/28/EC)** [11] which aims for a 20% share of energy from renewable sources in overall community energy consumption by 2020. Upgraded to biomethane and used as vehicle fuel, biogas becomes a very good solution to reach the mandatory 10 % minimum target to be achieved by all member states for the share of biofuels in transportation consumption by 2020, imposed by this renewable energy directive. Besides, this text plans that the contribution made by biofuels produced from wastes, residues, non-food cellulosic material, and ligno-cellulosic material shall be considered to be twice that of other biofuels, which makes the “fuel-grade biogas” use far more attractive. Biogas also meets the European organic waste management objectives enshrined in European regulations (**Directive 1999/31/CE on the landfill of waste**) that requires member states to reduce the amount of biodegradable waste disposed of in landfills and to implement laws encouraging waste recycling and recovery (**Directive 2008/98/EC on waste**.)

Biogas production is booming in Germany and has become Europe’s fastest growing renewable energy sector. Across the European Union, the rapid progress of the sector is obvious, as in 2009, primary energy growth increased by 4.3%.[2] No doubt that the **“gas” Directive (2009/73/EC)** has contributed to this surge. In fact, this directive invites all Member State to adopt concrete measures in order to encourage a stepped-up use of biogas, by extending the rules made for natural gas to the gas produced from biomass provided that all the safety standards and technical rules remain fulfilled.

Each of the 27 Member States had to submit a detailed national plan explaining how it intends to reach 2020 binding national renewable target. These plans offer an essential overview of member states’ strategies (support mechanism, technology choices, planning reforms, required investments, etc.) for the period 2011-2020. As far as biogas is concerned, all these European policies have prompted a number of member states to encourage its production and they have set up incentive systems for paying for electricity (feed-in tariffs, green certificates, tenders). The degree of ambition and details of these incentive actions vary from country to country.

[2] Biogas barometer – EUROBSERV’ER – NOVEMBER 2010

Most countries are interested in using biogas for combined heat and power (CHP) production in order to increase the supply of ”green” electricity. However, in Sweden, there is a strong interest in using biogas for vehicle fuel, due to the relative low prices on electricity and heat. In countries such as Denmark, Germany and Austria, the investors in anaerobic technology receive investment subsidies, a higher sale price on electricity or reduced interest on bank loans. These measures have clearly created incentives in these countries for building new plants.

Below is an overview of the regulations for some countries:

- In Germany, the **"Integrated Energy and Climate Program" (IEKP),** acts as the driver to reach the goal of reducing the green house gas emissions by 40 % in 2020 compared to 1990. The package consists of 29 concrete measures, which help to define the subvention programs and regulation concerning renewable energies. Germany is the leading European biogas producer, alone accounting for half of European primary energy output (50.5% in 2009) and half of biogas-sourced electricity output. This exceptional performance comes from the implementation of a feed-in tariff that combines a number of premiums. Since an incentive law giving biomethane suppliers priority to the grid came into force in February 2008, Germany has also started feeding biomethane into the natural gas grid. The law also transfers responsibility for a major part of the associated costs to the grid operators instead of being borne by the biomethane suppliers. This approach has resulted in an outstanding growth in biomethane injection. Currently, there are more than 6,000 biogas plants in Germany, of which 55 are injecting all or part of the gas produced into the natural gas grid.

- In the Netherlands, the program Clean and Efficient (**Schoon en Zuinig**) describes the climate goals for the Netherlands. The targets of this climate policy are: a reduction of greenhouse gas emissions by 20% compared to 1990, a rate of energy efficiency improvement of 2% per year and a share of renewable energy of 14% in 2020. To reach these ambitious targets in term of renewable energy, a new aid scheme called **SDE+** (“stimulering duurzame energie”) has been implemented, establishing financial compensations for renewable electricity or biomethane producers. The system is dedicated to subsidising those energy forms that result in the largest greenhouse gas reduction at the lowest cost. This means that the position of biomethane injection in the grid in SDE+ is strong. Feed-in tariffs have also been evaluated. To make it easier for the commercialisation of biogas, a green certificate system has been created, called Vertogas.

- In Sweden a lot of incentives for developing biogas are present. This energy is exempt from CO_2 tax and for each biogas plant, the government allocates a grant up to 30% of the amount of the total investment (Climate Investment Program Klimp). The biofuel vehicle also benefits from a 1100€ subsidy.

- In Switzerland, the national gas industry organisation has established a **clearing fund** to support biogas and since 2001 the “**Naturmade certification**” has been created to value electricity coming 100% from renewable sources. Other certifications are still being studied.

- In Denmark, a subsidy for biogas production of approximately 40 €ct/m^3 of methane is given. This amount is expected to increase to approximately 60 €ct/m^3 through new legislation 2012. In addition, a grant of 20% of the construction costs for new biogas production plants is given.

In 2011, approximately 4 PJ has been produced, which is equivalent to 2% of the natural gas supply. The production is expected to increase to 20 PJ in 2020.

- In the United Kingdom, market mechanisms have been established to support the biogas sector: Renewable Obligation Certificates (ROCs) has been implemented, as well as feed-in-Tariffs for electricity. Other programs have contributed to the growth of the biogas industry: the Waste Resources Action Programme (WRAP), the Bioenergy Capital Grant Scheme or the Rural Development Programme for England (RDPE). The Anaerobic Digestion plan 2010 with its £10 million programme helped to launch a lot of new projects.

- In France, the Grenelle II law sets the principle of a new feed-in tariff. Being more attractive, it should encourage investors and boost the biogas market. In fact, a series of incentives are currently under discussion to define the framework for biomethane injection opportunities: the implementation of a clearing fund, a system to guarantee the green origin of biomethane, technical specifications to inject it into the grid and specific feed-in tariff.

4.3. Situation in the United States

As far as the United States is concerned, a number of Federal programs and state programs primarily in California, Pennsylvania, Wisconsin and New York state have been the major drivers for the development of new aerobic digester systems in the U.S. Among these, the agricultural anaerobic digesters are the most widespread biogas technology.

The **AgSTAR Program**, a program from the United States Environmental Protection Agency (EPA), has been very successful in encouraging the development and adoption of anaerobic digestion technology and provides a sample of the federal incentives that can be leveraged to reduce financial barriers for the owners or operators.

The **Farm Security and Rural Investment Act** of 2002 and then the **Food, Conservation, and Energy Act** of 2008 established the Renewable Energy Systems and Energy Efficiency Improvements Programs. Under this program, the U.S Department of Agriculture (USDA) provides loans, loan guarantees, and grants to farmers, ranchers and rural small businesses to purchase renewable systems and make energy efficiency improvements. In 2010, USDA and EPA announced a new interagency agreement promoting renewable energy generation and slashing greenhouse gas emissions from livestock operations. This agreement will help to increase the number of biogas systems by finding ways to allow more farmers to tap into this resource.

Nevertheless, anaerobic digestion use remains much more prevalent in Europe where higher energy prices and government incentives have spurred widespread adoption of this technology. In the U.S., by contrast, historically low energy prices have retarded development of alternatives. Current government policies do not treat biogas as favourably as other renewable fuels. Biogas has never enjoyed the sort of political support or constituent base to mobilise action in Washington.

4.4. Situation in Asia and the Pacific

Although Russia shows a high potential for biogas production, it will have to change the internal policy in the field of renewable sources of energies and waste management in order to direct the country to a more sustainable path of development.

Driven by strong growth in countries such as China, India, Japan and Australia, the renewable energy sector in Asia Pacific is expected to grow rapidly in the coming years. Although diverse, the countries of the region are all aspiring to provide their citizens with modern energy supply while striving to meet the demands of rapidly developing economies.

China will lead the growth of renewable energy in the Asia-Pacific. The Chinese Government has established a target of generating 15% of electricity through renewables by 2020 and has also initiated support measures for small hydro and biomass facilities. This program has also the purpose to fight deforestation in central parts of China, the biogas produced by a small fermenter which is fed by domestic and agricultural waste material replacing firewood previously collected in a large area around the respective farm.

China, Australia and Japan use both Renewable Portfolio Standards (RPS) and feed in tariffs to promote renewables. In India there is no national level tariff or standards but the different states in the country have RPS targets and offer fixed tariffs for renewable electricity. Thailand offers additional fixed tariffs for small renewable energy projects. The country has also enacted a National RPS. The renewable energy industry in the country is still in its early development stages. However, Thailand's renewable energy industry is expected to grow at a fast pace in future with the government laying down the Renewable Energy Development Plan 2008-22. With huge biomass resources, the government expects biomass to play a leading role in this development.

Table 5 gives an overview of the supporting policies in Asia and the Pacific,

Table 5: Supporting policies for renewable energy in Asia and the Pacific

	AU	CN	IN	IND	JP	NZ	RU	TH
Feed in Tariff		√						√
Renewable Portfolio Standard	√	√		√				√
Capital subsidies, grants or rebates	√	√	√	√	√	√	√	√
Energy Production Payments/ investments or other tax credits		√	√					
Sales tax, energy tax, excise tax or VAT reduction		√	√					
Tradable renewable energy certificates	√				√			
Net Metering					√			√
Public investments loans and financing	√	√	√	√	√	√		√
Public competitive bidding		√	√					

Source: Asia-Pacific Energy Policy Handbook

5. Economical aspects

5.1. Economics of biomethane production

For a thorough evaluation of the economics of biomethane production, a single paragraph is insufficient. The costs are regionally diverse since labour costs, land prices as well as biomaterial prices vary by region. Another aspect that varies is the calorific content of the biomethane needed for injection in the grid, and also the costs attributed the connection to the gas grid may fluctuate. The length of the connecting pipeline and the pressure in the gas grid have a large influence on these costs.

The most detailed overview of the cost structure for biomethane production is given by the Fraunhofer Institute [21]. This overview originates from 2008. It is possible to make country and case specific calculations when using the source data from this report. For instance, every year, the Dutch government makes a calculation for the production costs of biomethane in order to calculate the height of the subsidy for production [22]. The cost figures of these calculations are in line with the data from the Fraunhofer Institute.

The cost estimates in the Dutch subsidy report for the year 2012 are given in Table 6. Note that the calorific value of the gas is 31.6 MJ/m^3. For the various biogas sources, different plant sizes are assumed based on the actual plant sizes in practice.

Table 6 Cost estimates for biomethane production for 2012 from the Dutch subsidy report.

Cost/source	Landfill	Manure co-digestion	Biowaste
Digestion			
Biogas production [m^3/h]	150	550	950
Production [hours/year]	6500	8000	8000
Heat demand	0 % of biogas	10% of biogas	10% of biogas
Electricity need [kWh/m^3]	0.15	0.25	0.25
Investments [M€]	0	2,3	3,7
O&M cost [k€/year]	0	141	210
Biomaterial costs [€/ton]	0	27	25
Gas treatment			
Investments [M€]	0.8	1.5	2.3
O&M cost [k€/year]	54	152	190
Biomethane production [m^3/h]	80	280	500
Overall costs biomethane [€ct/m^3]	36,3	74,8	61

5.2. Cost distribution

Up to now, biogas does not sell on its own without any incentive. To touch on the issue of biogas production and injection purely from an economics point of view would turn the entire issue down.

Its production is so far always more expensive than producing natural gas and transporting it to the producer. For example in Germany, whilst natural gas is available at a cost of 5 – 6 Euro-Ct/kwh, the same amount of energy based on biomethane will not be available for less than 9 Ct. Most incentives come from the governments which support biogas, but also other renewables for different political reasons, most of them being ecological, but also others factors such as the nationalisation of the energy supply.

There are several options for cost distribution:

- For direct subsidy, it is the tax payer. In this case, an elected government has to convince its electorate that it is doing the right thing when supporting biogas producers;
- By means of cost transfer to other branches of the industry, for example, the gas transport industry. To achieve this, a multiple legal framework is necessary to create conditions for biogas which are better than for the transport of natural gas. For example, in the EU, instead of a directive which provides "indiscriminative access" for biomethane in comparison to natural gas, some of its member states demand "preferred access" for biomethane, i.e. urging a grid operator to deny natural gas access to its grid if at the same time there is a request to transport biomethane. This model, however, implies cross-subsidies from one branch of the industry (gas industry) to another branch, an issue which formally is forbidden at least in the EU. However, there seem to be exceptions from the rule if the beneficiary is agriculture, as, in this case, it usually is. However, this can be avoided:
- By socialisation of the cost increase amongst the final gas customers. This is a very promising model. Not that already a significant share of gas consumers is eventually willing to pay a surplus for green biomethane instead of fossil natural gas. Besides, the general customer will not easily verify that part of increase of his gas bill is due to "averaging" the elevated costs from biogas injection over an entire market area, sharing them between the systems of several grid operators.
- By creating additional benefit. One model is to exempt non-fossil fuels from CO_2 taxation. This will increase the preparedness of (natural) gas traders to incorporate biomethane into their portfolio, and can be a major incentive for states which signed the Kyoto agreement but have major problems to fulfil its criteria with the sole objective to avoid punitive financial effects of CO_2 emission.

6. Environmental and social aspects

6.1. Environmental aspects

For every product it is important to minimise the negative environmental and social impact. Renewable gases are no exception. Aspects that should be addressed are among others: land usage, water usage, fertiliser usage, energy usage, carbon footprint and employability. In the process of renewable gas production, each step should be considered and optimised to reduce the negative environmental and social impact.

The following eight steps can be distinguished principally in digestion processes:

1. Biomass production and harvesting *(only for energy crops)*;
2. Wet biomass collection and transport;
3. If needed, pre-processing and storage of the substrate;
4. Feed regulation (substrate preparation and dosage) and fermentation (digestion);
5. Biogas treatment (and upgrading if biomethane production);
6. Biogas/biomethane storage or biomethane injection;
7. Biogas or biomethane valorisation;
8. Treatment, storage and use of digestate.

The results of the environmental assessment of biomethane production and utilisation can vary according to different factors such as:

Biomass supply: environment assessment can vary according to the type of biomass that is used.

- Waste: it is the most profitable substrate from an environmental point of view because:
    - its production does not have to be taken under consideration in environmental assessment (point 1 above);
    - its use enables avoidance of other waste treatments.
- Energy crops: As far as it is possible to convert the whole plant, the quantity of net energy produced per hectare is high. Here again, the performance of the approaches depends on what species are cultivated and how they are cultivated (cultivation and harvesting practices, type and amounts of agricultural inputs). Nevertheless, if sustainability criteria are met, the use of energy crops will reduce GHG emissions by replacing fossil fuels [4]. Second crops, or **catch crops**, planted after the harvest of the main crop, can also be used as biogas feedstock. This system allows two harvests per year on one piece of land. Green cuttings, material from landscape maintenance can also be used as biogas feedstock. This type of feedstock should be available within a small radius of the biogas plant, as the transportation of feedstock with high water content is costly, both from an economic and ecologic point of view.

Biomass water content: when waste or energy crops have high water content (such as liquid manure), they have lower yield and therefore should be processed close to where they are produced in order to save transportation costs[3] and emissions.
Biomass collecting distance: generally speaking, the emissions increase with the collecting distance.
Optimisation of the chain: it is important to minimise the emissions all along the chain of production and utilisation of the biomethane;
Biomethane valorisation;
Energy replaced: the results will be different if biomethane replaces coal or natural gas;

[3] Form an economical point of view, it is generally said that liquid manure must not be transported for more than 10 km.

By-product valorisation: the assessment results vary if digestate is used as a fertiliser or if it is considered a waste.
Greenhouse gas (GHG) emissions: biomethane is very interesting from the point of view of GHG emissions reduction (especially when it is created from waste). All analysis of the replacement of fossil fuels by biomethane from wastes highlight the reduction of greenhouse gas emissions achieved accordingly:

- at the end-use step (combustion of fuel), as CO_2 emissions from biomass wastes (like those from all kinds of biomass) are considered as neutral with respect to the greenhouse effect,
- at the production step, as the anaerobic digestion of organic wastes enables the elimination of CH_4 emissions which occur when wastes, animal breeding effluents, etc. are stored.

Local emissions: the environmental assessment is not always profitable to biogas production depending on very local conditions and hypotheses (as an example, how digestate is treated and handled). For this reason, it is important to optimise the biogas and digestate production and valorisation chain [1].

With the steady increase in oil prices and improved legal framework conditions, “energy crop” research and development was again stimulated in the 1990s. In Germany for example, the number of digesters using energy crops has increased from about 100 in 1990 to nearly 4,000 in 2008 [4]. However, no single crop can cover all specific requirements of the various local conditions.

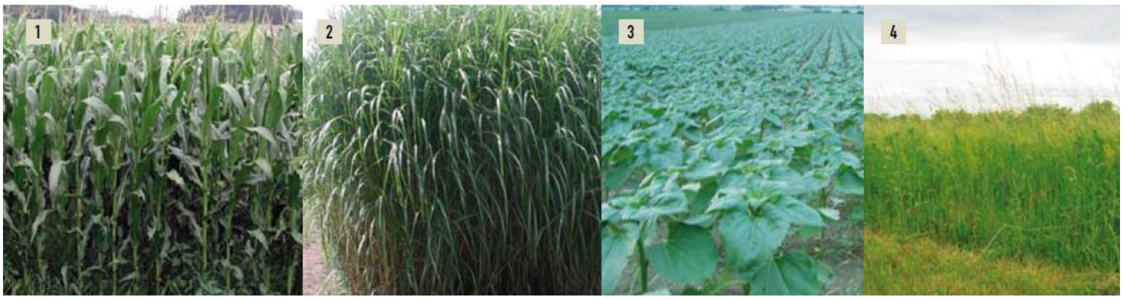


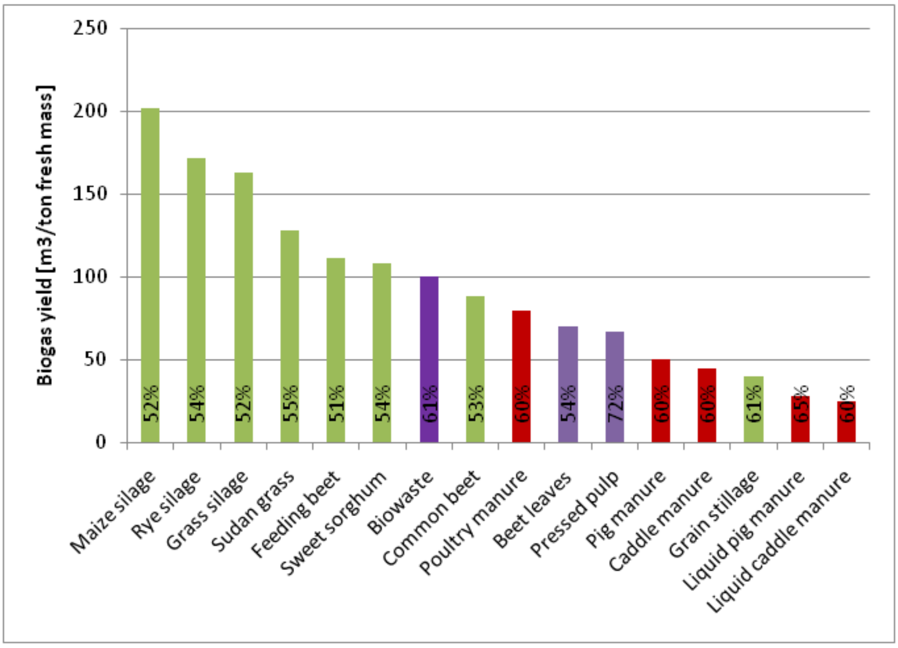
Figure 7: Examples of energy crops: (1) maize, (2) miscanthus, (3) sun flower, (4) grass

Comprehensive investigations for the selection of optimised plantation systems for different habitats have been started in some countries such as Germany, Netherlands or Austria [4]. Results so far demonstrate a considerable influence of the soil quality, climate, water availability, crop rotation and last but not least the harvest time on the biomass yield, the methane production and consequently on the overall economic process viability.

High water content impacts the biogas yield per ton fresh mass as illustrated in Figure 8. The figure shows that maize silage has the highest biogas yield of the described feedstock (waste such as grease or molasses offer an even higher biogas output).

Another good measure to compare overall yields is the energy yield per hectare of cultivated land (see Table 7).

Figure 8: Different substrates can be used for biomethane production by methanisation



Source: AEBIOM

Table 7: Rough calculation of net energy yield and output / input ratios, for a wide range of calculable methane yields per ha, respectively selected examples of crops

	Maize	Potatoes	Fodder beet	Oilseed rape	Rye
Methane yield [m^3/ha]	9 886	10 258	9 450	1 442	814
[MJ/ha]	353 919	367 236	338 310	51 623	29 141
Process energy demand for digestion	-53 088	-55 085	-50 746	-7 745	-4 371
Energy requirement in cropping	-16 800	-24 200	-20 350	-16 800	-16 800
Total energy requirement	-69 888	-79 285	-71 096	-24 545	-21 171
Net energy yield [MJ/ha]	284 031	287 951	267 214	27 078	7 970
Output/Input ratio	5.1	4.6	4.8	2.1	1.4

6.2. Sustainability of biomass

From the sustainability of biomass point of view, two cases have to be considered:

- biogas and biomethane production from *waste*: as no natural resources are used, this supply is very sustainable. Furthermore, it permits the creation of energy and the treatment of waste at the same time, which makes it an even more interesting proposition.
- biogas and biomethane production from cultivated *wet and dry biomass*: this is more delicate. The biomass should to be cultivated in a sustainable way in order to ensure that its environmental impact is positive to the planet.

Generally speaking, some elements that should be taken under consideration to define biomass sustainability are:

- biomass harvesting locations (in order to prevent growth in nature protection areas, biodiverse grasslands and peatland). Even soils not suitable for food production can be used for the cultivation of energy crops and dry biomass. Indeed cultures that are net sequesters of carbon can be produced on agriculturally degraded lands and will neither displace food production nor cause loss of biodiversity [4].
- the frequency of biomass harvesting;
- water consumption,
- fertiliser consumption,
- soil depletion[4],
- supply chain

It is important also to avoid competition with food production as much as possible[5]. In this sense, the use of bridging or catch crop is under study. The advantage is that biogas can be produced from plants without being in competition with food production. However, the crop most used in Germany is maize, which, alongside with its strong methane potential, has some drawbacks such as irrigation needs, rising prices and competition with food supply.

It is therefore essential to identify plants that will make it possible to produce biomethane more sustainably (alfalfa, sorghum, etc.). Research is necessary on the selection of the crops (and the combination of different crops) to both maximise the biogas production and minimise the impact on environment.

As a consequence, energy crops should be carefully selected, depending on local climate conditions, availability of irrigation water, robustness against diseases and last but not least – based on biomass yield per hectare.

The CEN Technical Committee (TC) 383 *Sustainability produced biomass for energy applications* was created in 2008 in order to work on European Standards dealing with sustainability principles, criteria and indicators including their verification and auditing schemes for biomass for energy applications. This includes green house gas emission and fossil fuel balances, biodiversity, environmental, economic and social aspects and indirect effects within each of the aspects. The Renewable Energy Directive (2009/28) sets the framework for the scope of the work of TC 383.
It has to be noted that the Renewable Energy Directive states that in order to consider sustainable biofuels, the greenhouse gas emission saving from their use must be at least 35 %[6]. Moreover, biofuels taken into account must not be made from raw material obtained from land with high biodiversity value[7]:

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[4] Currently most energy crops (as well as most important food crops), are grown as intensive monocultures. Annual monocultures are often associated with high rates of soil erosion. Some crops, like maize, deplete soil nutrients more rapidly than others, and might require significant levels of agrochemicals (fertilizer, pesticides) unless the digestate is carefully recycled (see § 6.5).

[5] This more frequently concerns wet biomass (such as maize) than dry biomass

[6] From 2017: > 50 %; from 2018: > 60 % (for biofuels produced in installations in which production started on or after 1 January 2017).

[7] Such as: primary forest and other wooded land, areas designated for nature protection purposes or for the protection of rare, threatened or endangered ecosystems or species, highly biodiverse grassland.

6.3. Standardisation works on biogas

ISO has set up two different technical committees related to the use of renewable biomass and biogas. ISO/TC 248 "Sustainability criteria for bio energy", created in 2011 are developing standards in the field of sustainability criteria for production, supply chain and application of bio energy. This includes terminology and aspects related to the sustainability (among others: environmental, social and economic) of bio energy. A similar work had already been started in Europe in 2009 within CEN TC 383 and has achieved some results with the circulation of draft standards prEN 16214 part 1 to 4.
ISO/TC 255 "Biogas" has been launched at the beginning of 2011 to develop standards in the field of biogas, including the design, construction, check and acceptance of installations, plants, equipments and products, the integrated utilisation, the development and application models, the technical and economic assessment and environment benefits assessment.
As already stated, CEN PC 408 has been created following the mandate M 475 by which the European Commission asks that standards for biomethane injection in the grids and use as vehicle fuel be prepared.

6.4. Other social aspects

Biomethane production leads to the creation of local (and difficult to shift abroad) employment. As an example, the French Energy Environment Technical Association (ATEE club biogaz) has assessed that more than 12°000 person-year and 5 000 permanent jobs have been created in France from 2005, of which more than 2/3 difficult to be relocated [6].

Furthermore, the cultivation of energy crops promotes rural investments and creates new jobs. In the RES Directive, the benefits of biogas production are recognised:
“The use of agricultural material such as manure, slurry and other animal and organic waste for biogas production has, in view of the high greenhouse gas emission saving potential, significant environmental advantages in terms of heat and power production and its use as biofuel. Biogas installations can, as a result of their decentralised nature and the regional investment structure, contribute significantly to sustainable development in rural areas and offer farmers new business opportunities.”

6.5. By-products valorisation

6.5.1. Digestate utilisation

Anaerobic digestion is an effective way to treat organic wastes from households, municipal authorities, organic solid wastes from industry and agricultural residues. Besides biogas, the end products of anaerobic digestion are liquors and solid organic materials [18].
The following products are distinguished:

- Separated fibre: the fibrous fraction of material derived by separating the coarse fibres from whole digestate. At least 15% of its mass should be dry matter.
- Separated liquor: liquid fraction of material remaining after separating coarse fibres from whole digestate. Less than 15% should be dry matter.
- Whole digestate: material that has not undergone a separation step.

There is a market for all of these products.
Whole digestate could be aerobically stabilized and be used as compost or be used as an input for the composting process to produce nutrient-rich compost.
Whole digestate from wet agricultural wastes can be used as a soil conditioner, adding nutrients and soils, suitable for arable crops.
Fibre can be used as a soil conditioner, adding bulk and improving water drainage of soils while liquor is a fertilizer, adding and increasing the nitrogen uptake [19].

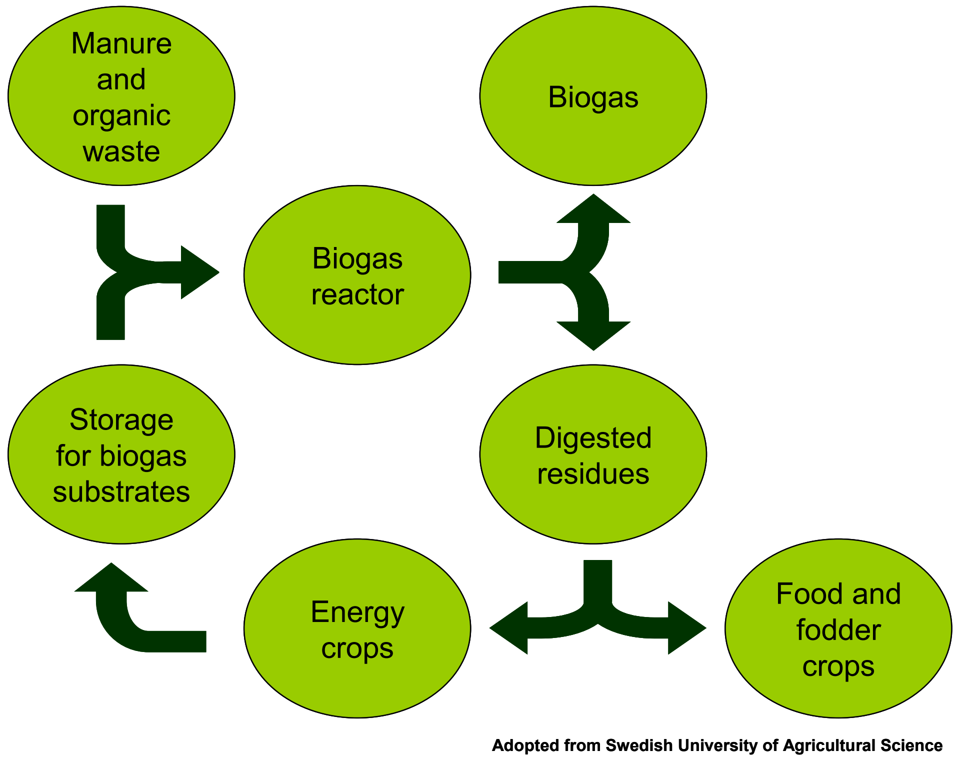
Quality protocols for the production and use of digestates have been established in several countries. One example is the PAS 110:2010 that was made in cooperation with the British Institute of Standards (BSI) [20]. This protocol contains guidelines for the input materials, the processing of the material, the process equipment, the process monitoring, the sampling of the digested materials and the quality requirements for the digestate.
In PAS 110:2010 the following items are recommended for validation:

- Pathogen content
- Toxic elements (e.g. cadmium. Chromium)
- Stability (residual biogas potential and volatile fatty acids)
- Physical contaminants (glass, plastic and metal fragments)
- PH
- Nitrogen, Phosphorus, Potassium, ammonia, chloride, sodium
- Dry matter

The market value of the digestate materials is low. The Environment Agency (UK) mentions a negative price of 5 £/ton including transport. Another source mentions a value of zero or slightly positive, so biogas plants do not pay others for accepting digestate.

The use of digestate has some environmental benefits, such as limiting inputs of chemical fertilisers, thanks in particular to the high mineralisation of the nitrogen in the product and the preservation of the fertilising value of the treated waste. However, in some local contexts, using the digestate may not be environmentally friendly because of, for example, the risk of volatilisation of the nitrogen during spreading [1].

Figure 9: Process cycle of anaerobic digestion



Under certain conditions, the digestate produced by the anaerobic digestion of organic wastes or energy crops can be used as an organic fertilizer on cropland [3].

6.5.2. Heat utilisation

Biomass gasification produce an important amount of heat: it can be important, from an economical and an ecological point of view to valorise it.

6.6. Emissions & Life Cycle Analysis

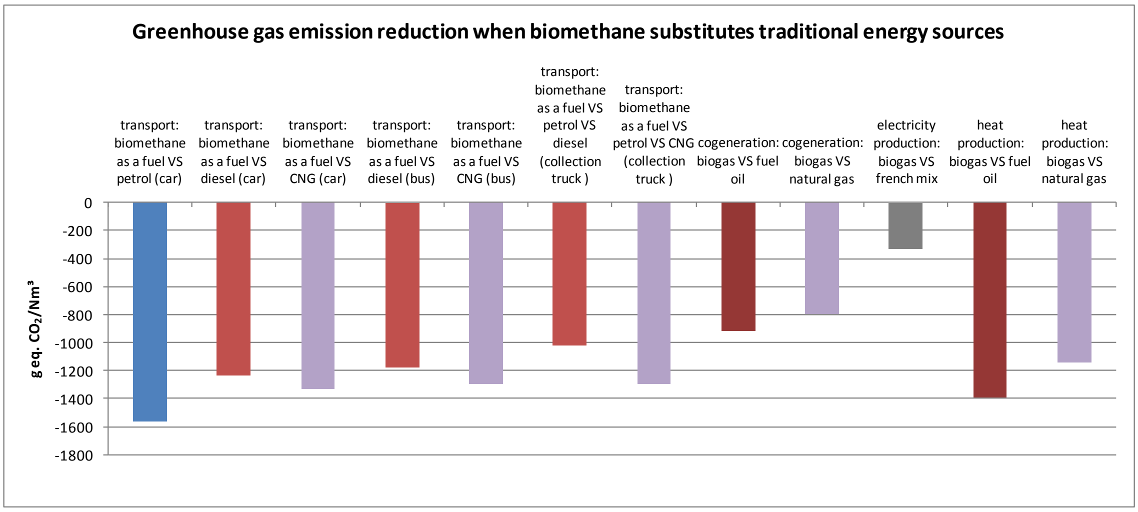
6.6.1. Anaerobic digestion

The French Environment and Energy Management Agency (ADEME) and GDF SUEZ have realised a Life Cycle Assessment (LCA) [2] of biogas and biomethane production and utilisation concerning both:

- the *transport* sector (car, bus and collection truck);
- the *heat and electricity production* sector (cogeneration, heat production and electricity production).

Biogas and biomethane emissions have been compared to the more traditional energies sources, such as fossil fuels and the French energy production mix.

Figure 10: Greenhouse gas emissions reduction (on a life-cycle base)
- Use of biogas and biomethane versus traditional energies sources

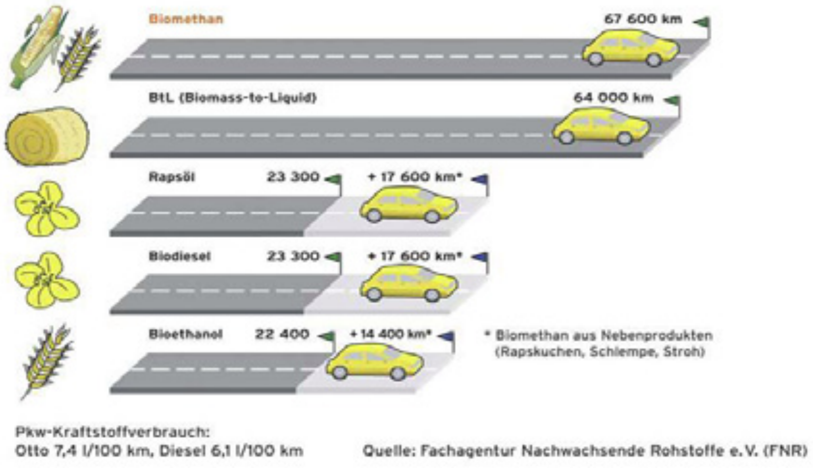


Note: Traditional energy sources for *Transport sector:* petrol, diesel and CNG and for *Heat and Electricity sector:* fuel oil, natural gas and French electricity mix production

When biogas and biomethane replace traditional energies sources, the greenhouse gas emissions (on a *life-cycle* base) are considerably reduced [2].

Other studies highlight the land use efficiency of biomethane production when compared to liquid production for vehicle fuel (see Figure 11)

Figure 11: Comparison of biofuels production (FNR) from the same surface



6.6.2. Gasification

Similarly to the anaerobic digestion, in gasification processes, the following steps can be principally distinguished:

1. Biomass production and harvesting *(with the exception of forest and industrial residues)*;
2. Dry biomass collection and transport;
3. Biomass pre-treatment and storage;
4. Gasification, methanation and upgrading;
5. Biomethane injection;
6. Biomethane valorisation;
7. Disposal of ashes and excess carbon

Biomethane production through biomass gasification is in R&D phases. For this reason, fewer publications on its environmental performances are available. Two LCA (the one based on a UK case [9] and the second a Swiss case [10]) have nevertheless been published.

Basic results demonstrate that bioSNG production and use in commercial and domestic heating, industrial CHP and road transport achieves substantial net GHG emissions savings relative to fossil fuel alternatives consisting of natural gas and fuel oil-fired heating and CHP, and diesel and petrol for road transport [9].

Actual net GHG emissions savings depend on:

- the assumed default values in the workbooks (specifically a round trip distance of 20 km for delivery of biomass feedstock to the bioSNG plant),
- the GHG emissions calculation methodology applied
- the specific choice of biomass feedstock.

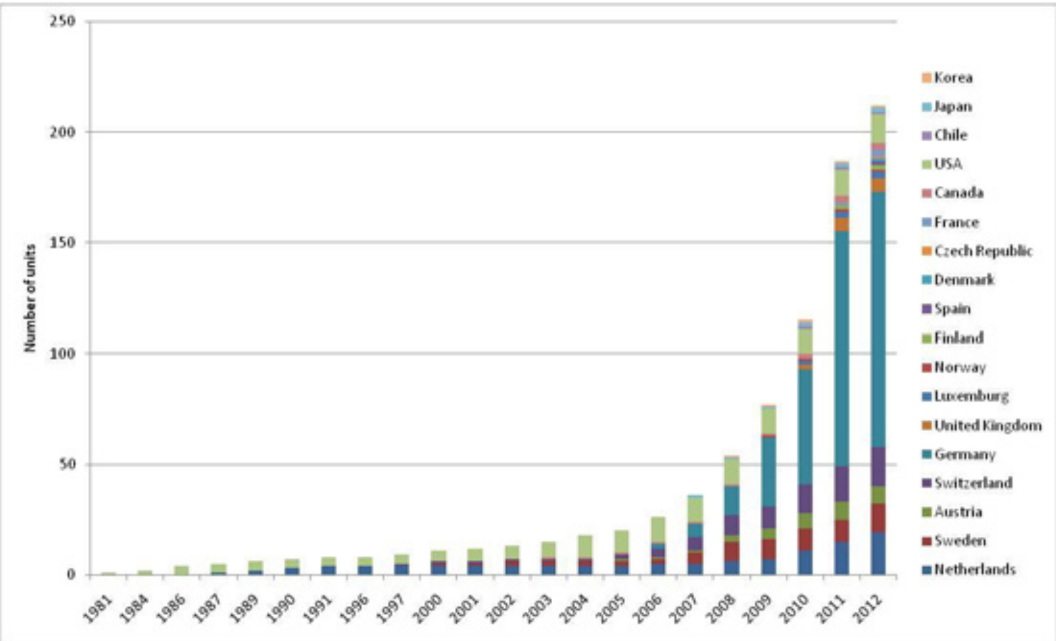
7. Current situation, potential and prospective

7.1. Situation in Europe

7.1.1. Current situation

European primary biogas energy output rose into 8,3Mtoe in 2009, which is 346,8ktoe more than in 2008. Within Europe, biogas energy is mainly recovered in the form of electricity. In 2009, 25.2 TWh were produced from biogas, which is an increase of 17.9% on 2008. A German study "The Market for Biogas Plants in Europe" published by Ecoprog and the Fraunhofer UMSICHT Institute puts the number of anaerobic digestion plants operating at the beginning of 2010 at about 5 900, with combined electrical capacity of 2 300 MW. The study forecasts that a further 3 000 plants will be constructed by 2013 adding 1 700 MW and that by 2018 they will be joined by another 3 500 plants adding 1 800 MW of electrical capacity. Figure 12 shows the development of the number of biogas production units in several countries.

Figure 12: Number of biogas production units by Countries



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Source: GDF SUEZ CRTGEN

Electrical and thermal conversion of biogas are not the only research area. The Swedish and Germans, for example, have instigated their own industries to produce biomethane for feeding into the natural gas grid. The development of “fuel-grade biogas” (natural gas quality) provides another opening, but it is harder to set up because it requires heavy investment on infrastructures and a filling station conversion program.

For several years now, the main (52%) European biogas energy deposit has consisted of purpose-designed anaerobic digestion plants for energy recovery. The main reason for the impressive growth of this channel is the development of agricultural anaerobic digestion plants whose production increasingly relies on **energy crops**. These plants now produce much more than **landfill plants** (36%) and **wastewater treatment plants** (12%). Of course, it depends on the member state: some (egthe United Kingdom) have plumped for landfill biogas energy recovery, whereas some others (egGermany) are banking on agricultural biogas recovery.

Indeed biogas production in Germany relies to a large extent on dedicated energy crops such as maize, even if the use of maize as a biogas feedstock remains particularly controversial. In some regions, even the federal government speaks about the "maization of the landscape", cutting the maize proportion for any new-built biogas plant at 50% in its latest revision of the "renewable energy law" (EEG). As a result, the country had about 5 000 anaerobic digestion plants with 1893 MW of electrical capacity in 2009 and this number should rise to 7000 in 2011, raising accumulated capacity to 2300 MW. Germany already had 35 enrichments plants in 2009 feeding 190 million Nm^3 of biomethane. In mid-2011, a further 20 have been connected to the grid raising biomethane production to 380 million Nm^3. The German Biomass Research Centre (DBFZ) puts Germany biomethane output potential at between 11.5 and 13.9 Mtoe per annum, which needs to be compared with its natural gas consumption of 76.6 Mtoe per annum. Germany aims to feed 6 billion Nm^3 of biomethane into the grid by 2020, which will call for the construction of 2 000 biogas enrichment plants according to the German Energy Agency. In order to increase biomethane injection, the reviewed EEG is lowering the subsidies and thus the price for electric power production from biogas on the same location in comparison to biomethane injected. On the other hand, to take load from the grid operator, the biogas producer will have to take care of the marketing of the biomethane, i.e. will have to present also a point where an amount of gas equivalent to the biogas fed in is leaving the grid.

The German market is no longer Europe's sole market driver as more and more countries are preparing the ground for developing their own national industry. Italy's growth forecasts are particularly high, and they should be matched by those of France, Spain, Sweden, Denmark and the UK. Besides, new markets are emerging in Eastern Europe such as the Czech Republic, Slovakia and Hungary.

Italy was Europe number four producer in 2009 after Germany, the UK and France with 444.3 ktoe, as primary energy production increased by 8.4% over 2008 and electricity production by 8.8%. As was said previously, the UK prefers to rely on energy recovery from landfill biogas. The country produced 1723.9 ktoe of biogas in 2009 and 1474.4 ktoe were landfill biogas (85.5%).

France's biogas potential is hardly tapped. Most of the energy produced (526.2 ktoe in 2009) comes from biogas trapped directly in non-hazardous waste repositories (84% of the total) and for the most part, this deposit is still under-exploited. There are 300 landfills in France, 200 of which trap biogas but only 65 of them convert it. In 2009, there were also 74 urban wastewater plants and 90 effluent treatment stations that digested sludge primarily to produce heat and some electricity. Farm installations are also under-represented. So in 2009, biogas electricity output production was only 846.4 GWh, which is a fraction of German or UK output. The first biomethane injection into the grid is expected in France in the beginning of 2011, whereas biomethane injection is practised in the Netherlands since 20 years and is now even ready to feed the regional grid. Sweden is also particularly active in this field with more than 40 enrichments plants at the end of 2009 but only 7 of them are already feeding biomethane into the grid (19 Mm^3/year).

7.1.2. Prospective

A study funded by the European Environment Agency shows that the European Union is set for a sharp increase in electricity production from biogas. This should rise from 27.8 TWh in 2010 to 56.4 TWh in 2020, which equates to a mean annual growth rate of 7.3%. Germany is planning to be the top contributor in Europe (23.4 TWh), ahead of Italy (6 TWh) and the UK (5.6 TWh). Over the same period the electrical capacity of these installations will rise from 5177 to 9 528 MW, while the production of recovered heat will rise from 1.4 to 3.8 Mtoe

(including 1.7 Mtoe in Germany). The report does not specify the amount of biomethane that will be fed into the grid.
In Denmark, the first biogas plant with injection of biomethane into the natural gas grid was commissioned in 2011. Two more plants with a production capacity of approximately 13 mln. m^3 of biomethane each are expected in 2012-2013.

7.2. Situation in the United States

In the U.S., due to strong federal and state incentives, two-thirds of the landfill gas goes to electricity production. Nevertheless, due to a lack of economic incentives and important legal, logistical and technological challenges, a very limited amount of biogas is upgraded to natural gas quality. Only a couple of small domestic companies are present in this market segment. Besides, most of the programs aim to manage animal waste to recover methane but the other types of biomass seem to be isolated. In fact, anaerobic digestion of livestock manure is steadily increasing across the United States. A recent EPA survey identified 147 manure digesters on farms across the U.S., with over 80% on dairy farms. The U.S. Department of Agriculture and dairy industry agreed to reduce carbon emissions at dairies by 25 percent by 2020. To meet this commitment, manure digesters may be built at more U.S. diaries. Still, a number of large communities in the United States have undertaken feasibility studies evaluating anaerobic digestion as part of "New and Emerging Technologies" or "Conversion Technologies" to treat municipal waste and it appears that the number of municipal solid waste facilities will rise quickly.

7.3. Situation in other countries

Turkey’s situation is still at the beginning of the process, with only 20 biogas plants and no biogas upgrading plant. The produced biogas is only separated from condensate and hydrogen sulphide to be used in gas engines. It seems that market players are waiting for the new legislation and the potential feed-in tariff. Turkey has a rather significant biogas potential with 2000 estimated plants only with animal manure even if there are still no on-farm installations.

Biogas industry in Canada is growing: currently 20 farm digesters are operating across the country. The trend in Canada is to use waste residues as co-substrates with manure, with less emphasis on co-digesting manure with energy crops. Provincial and federal governments are committed to fostering adoption of farm based biogas plants, thanks to feed-in tariff program for example, which offers guaranteed pricing for renewable electricity production. Nevertheless, significant differences in anaerobic digestion industry between provinces remain and the lack of clear economic driver slows down the development of the biogas sector. Besides, energy policies are primarily a provincial responsibility. Thus individual small industry, farmers groups or individual farmers are essentially on their own to lobby and advocate. Several studies are being conducted to investigate environmental impacts associated with on-farm manure digesters and a growing interest in biogas upgrading has finally to be mentioned.

Anaerobic digestion technology is well developed worldwide. Of the estimated global anaerobic digestion capacity, Asia accounts for a large part since traditional, small, farm-based digesters have been used in China, India and elsewhere for centuries.

8. Recommendations and Conclusions

Renewable gases are an opportunity for gas companies and the gas sector as a whole. By greening the portfolio it can decrease the environmental footprint of the gas industry and also open new segments for gas companies.

The underground natural gas network is the most energy-efficient and environmentally friendly way to transmit renewable gases as biogas and biomethane.

Technology

To produce renewable gases, many proven technologies are available. The choice should be made taking into account the nature of the biomass, the quantity of renewable gas produced and the end quality of the gas, to obtain the optimal technical and economical solution complying with applicable regulation.

The production of renewable gases is growing fast in many countries. The production coming from waste is however limited by the amount of waste available. To play a major part in the energy mix, production by gasification and by sustainable biomass should be further developed.

Biogas can be distributed in a dedicated grid or fed into the natural gas system with or without upgrading to biomethane. Each choice has its own advantages and disadvantages and the best technical choice depends on the local or regional circumstances. Close cooperation between producers, grid operators and consumers, especially industrial users, is necessary to find solutions that are not only technically possible because of the specifications for the gas mixture, but also financially attractive for all partners.
In markets with a well developed natural gas infrastructure, the tendency is to upgrade the biogas to biomethane. In emerging gas markets, the direct use of biogas is more common.

Gas industry and gas appliance manufacturers are encouraged to develop new smart gas grids fit for biogas or mixtures of renewable gases and natural gas. In these grids they should find solutions related to situations where the demand is lower than the renewable gas production in the gas grid involved.

Gas grid operators should be involved in monitoring the quality of the injected gases to ensure the safety and applicability for end-users and the integrity of the grid.

The quality of biomethane differs only a little from that of natural gas and therefore the existing gas network is capable of transmitting biomethane to gas consumers connected to the natural gas grid. In addition, the gas network serves as a gas storage facility and natural gas can be used flexibly as a back-up fuel for biomethane.

Biomethane can be used in all the same applications as natural gas. It is particularly suitable for distribution for use as a transport fuel via the natural gas filling station network. Therefore, no additional investments are needed in the transportation logistics of biomethane or gas-fuelled power plants and other appliances.

Policy, legislation and finance

The sustainable development of renewable gases calls for the introduction of appropriate governmental policy and legislation and promotion of renewable gases as a contribution to mitigate climate change. In developing this framework, the gas industry should take a pro-active attitude and help increase public awareness.

In developed natural gas markets, currently the costs of producing renewable gases are higher than for natural gas. Economic incentives are necessary to stimulate the renewable gas market. In major natural gas producing countries, because of the low price of fossil fuel, the development of renewable gas will need a change in the internal energy policy.
In emerging gas markets, the direct use of biogas competes economically with the use of coal, briquettes or kerosene.

The gas industry should be involved in setting up and publishing specifications and standards to ensure safe and reliable production, transport and use of renewable gases.

In order to obtain an open market for renewable gases, a certification system should be encouraged. As the gas markets are more and more integrated, such a certification system should raise from national level to become international.

Environment and society

In order to quantify the environmental footprint decrease and to ensure the sustainability of the renewable gas chain, life cycle analyses (LCA) should be conducted.

The introduction of renewable gases brings new environmental and social aspects into the gas industry. The sustainability of the biomass used is essential for the success of renewable gases.

Biomethane production leads to the creation of local (and difficult to shift abroad) employment. Biogas installations can, as a result of their decentralised nature and the regional investment structure, contribute significantly to sustainable development in rural areas and offer farmers new business opportunities.

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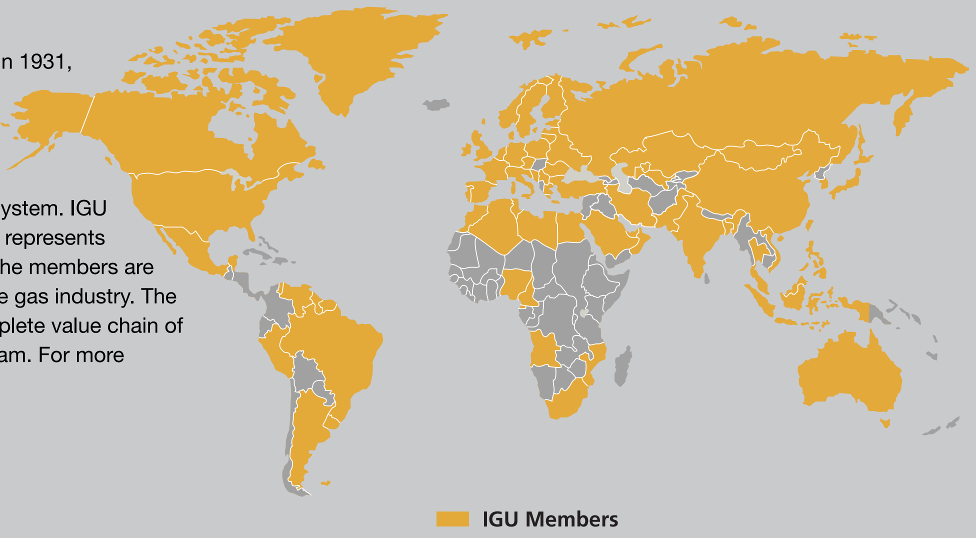
IGU

The International Gas Union (IGU), founded in 1931, is a worldwide non-profit organisation promoting the political, technical and economic progress of the gas industry with the mission to advocate for gas as an integral part of a sustainable global energy system. IGU has more than 110 members worldwide and represents more than 95% of the world's gas market. The members are national associations and corporations of the gas industry. The working organization of IGU covers the complete value chain of the gas industry from upstream to downstream. For more information, please visit www.igu.org.



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