Overview and Categorization of European Biogas Technologies

- Application of Biogas -

Author(s):	Franz Kirchmeyr (AKBOE) & Bernhard Stürmer (AKBOE)
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DiBiCoo – Digital Global Biogas Cooperation
Grant Agreement N°857804

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Executive Summary of D 2.2

The following document gives an overview of existing European biogas technologies.

The structure following the introduction section about Anaerobic Digestions (AD) follows the biogas processing logic: from feedstock storage on site and necessary pre-treatment to the various digester technologies. Special chapters on important elements of any biogas plant are elaborated in detail (e.g. on measurement, control and regulation technologies).

Upgrading biogas to biomethane quality as well as various application of Biogas are introduced (e.g. its GHG mitigation potential, as Combined Heat & Power (CHP) plants).

Due to the huge amount of existing information and knowledge on this topic it may occur that not everything is included or considered extensively. We propose this deliverable as a solid starting point getting to know about anaerobic digestion. This doesn´t replace special training courses and at least professional planning. In order to incorporate more relevant technologies and Biogas applications, some sections already outlined in this technology overview (e.g. on various pumps, pipes and valve types; or safety equipment) will be presented in an updated version later in October 2020.

The detailed descriptions of certain technologies are not implying any preference to a technology, service provider or device. Similarly, pictures including company names shall not be seen as a preference to any specific company or technology. It is done for visualization purposes only.

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Summary of the DiBiCoo Project

The **Digital Global Biogas Cooperation (DiBiCoo)** project is part of the EU’s Horizon 2020 Societal Challenge ‘Secure, clean and efficient energy’, under the call ‘Market Uptake Support’.

The target importing emerging and developing countries are Argentina, Ethiopia, Ghana, South Africa and Indonesia. Additionally, the project involves partners from Germany, Austria, Belgium and Latvia. The project started in October 2019 with a 33 months-timeline and a budget of 3 Million Euros. It is implemented by the consortium and coordinated by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH.

The overall objective of the project is to prepare markets in developing and emerging countries for the import of sustainable biogas/biomethane technologies from Europe. DiBiCoo aims to mutually benefit importing and exporting countries through facilitating dialogue between European biogas industries and biogas stakeholders or developers from emerging and developing markets. The consortium works to advance knowledge transfer and experience sharing to improve local policies that allow increased market uptake by target countries. This will be facilitated through a digital matchmaking platform and classical capacity development mechanisms for improved networking, information sharing, and technical/financial competences. Furthermore, DiBiCoo will identify five demo cases up to investment stages in the 5 importing countries. Thus, the project will help mitigate GHG emissions and increase the share of global renewable energy generation. The project also contributes to the UN Sustainable Development Goals (SDG 7) for ‘Affordable and clean energy”, among others.

Further information can be found on the DiBiCoo website: www.dibicoo.org.

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Content

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List of Abbreviations

AD	Anaerobic digestion
CHP	Combined Heat & Power
EU	European Union
ppm	Parts per million
VS	Volatile solids

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1 Application of Biogas

Biogas is a very versatile renewable energy source which offers several advantages and several applications. Possible applications are

- Raw biogas (with minor purification)
  - Heating & Cooking
  - CHP: combined heat & power production
  - Gen-set, a gas engine coupled with a generator for electricity production
  - Transport fuel
- Biomethane upgraded from biogas
  - Gas grid injection
  - Transport fuel
  - CHP: combined heat & power production
  - Heating & cooking
  - Raw material for chemical industry

The most common application within Europe is the electricity production via CHP and the use of produced heat for self-demand and district heating. However, upgrading biogas to biomethane and gas grid injection is a fast-growing market.

Produced biogas has the same temperature as the digester content and is saturated with water vapor. When biogas starts cooling, e.g. in gas pipelines, water vapor starts condensing, but biogas is still saturated with water vapor. Both characteristics can cause malfunction or even damage, e.g. when condensed water blocks the piston. Therefore, it is important to remove condensed water at the lowest point of gas pipes, to avoid that water can flow into the CHP (or other devices where it could cause damage) and to reheat the biogas before critical application so biogas will not be saturated with water vapor anymore (which could start to condense and could damage the following CHP).

The most valuable content for further application is methane, and to a lower portion hydrogen. Hydrogen sulfur and ammonia would also bring energy yield but can also cause unwanted emissions or even damage of devices. So usual biogas has an energy content between 5 and 7 kWh_{Hi} per m^3, mainly determined by the methane content. The main components of biogas are shown in Table 1.

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Table 1: Biogas: components and their properties (Nm^{-3}: 0°C 1013 mbar); © ÖNORM S2207, ÖVGW GB 220.

Component		Energy content [kWh_{Hs} Nm^{-3}]	Energy content [kWh_{Hi} Nm^{-3}]	Energy content [kWh_{Hi} kg^{-1}]	Density [$kg\ m^{-3}$]	Share within biogas [$\%_{vol.}$]
Methane	[CH_4]	11.06	9.97	13.85	0.72	50 – 70
Carbon dioxide	[CO_2]				1.977	30 - 50
Nitrogen	[N_2]				1.25	0 - 5
Hydrogen Sulfide	[H_2S]	7.03	6.48	4.22	1.536	0 - 2
Hydrogen	[H_2]	3.54	2.99	33.28	0.09	0 - 1
Oxygen	[O_2]				1.429	0 - 1
Ammonia	[NH_3]	4.82	3.99	5.17	0.771	0 - 2

1.1 GHG mitigation potential

Biogas is a valuable renewable energy source which offers a high potential to mitigate greenhouse gas (GHG) through digesting different kinds of organic material.

In order to fight the climate change, GHG emissions need to be reduced drastically as also agreed in in the Paris Agreement. Achieving this goal requires tremendous efforts from all sectors that emit greenhouse gases. In agriculture the storage of excrements from husbandry is a predominant source of GHG emissions, but on the other side also a major source to produce renewable energy via anaerobic digestion as the following figures show.

Following the biogas production process, the GHG mitigation potential of AD originates from many pathways. Below are only a few of them described.

1.1.1 Treatment of farm fertilizer

Figure 1, Figure 2, and Figure 3 give an overview of average daily excrements, GHG emissions and possible energy yield via anaerobic digestion of excrements from different animal species. All data are derived from National Inventory Reports of the respective countries. Firstly, Figure 1 gives an overview of the amount of daily excrements of husbandry from different European countries. Depending on the animal species, diet, climate conditions and animal performance, the amount of daily excrements from animals varies highly.

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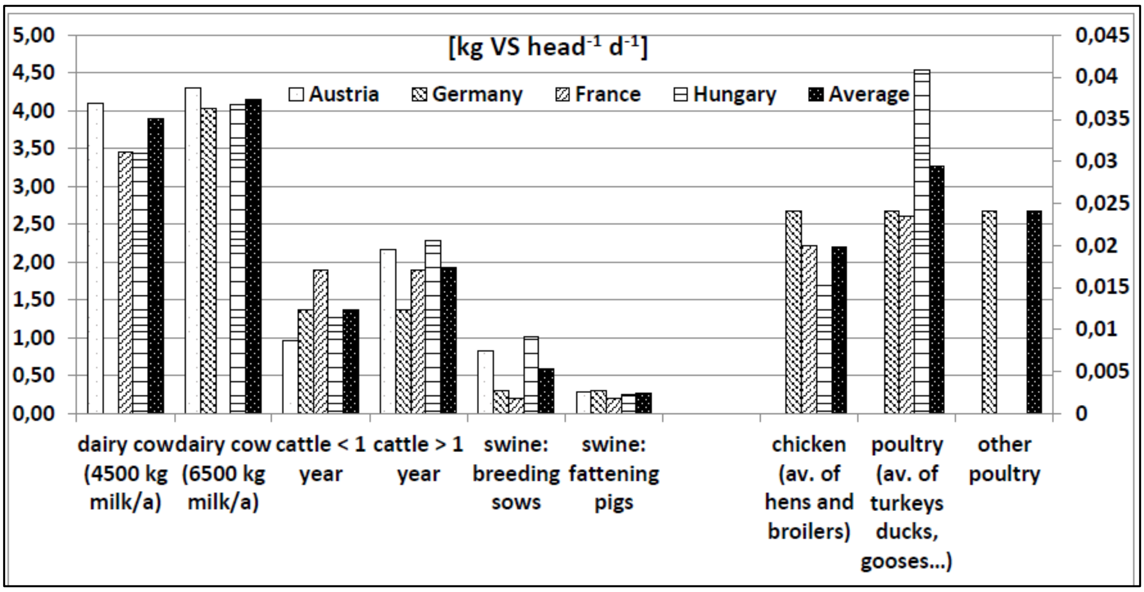

Figure 1: V_{Si} (average daily volatile solids) excreted (kg) from animal species - per country and animal category [kg VS head-1 d-1]; © Kirchmeyr 2016.

Based on excreted average daily volatile solids, climate conditions, husbandry and manure management, the average amount of CH_4 and N_2O emissions can be calculated. The latter is based on methods described in the IPPC report (IPCC - Ch 4, 2000).

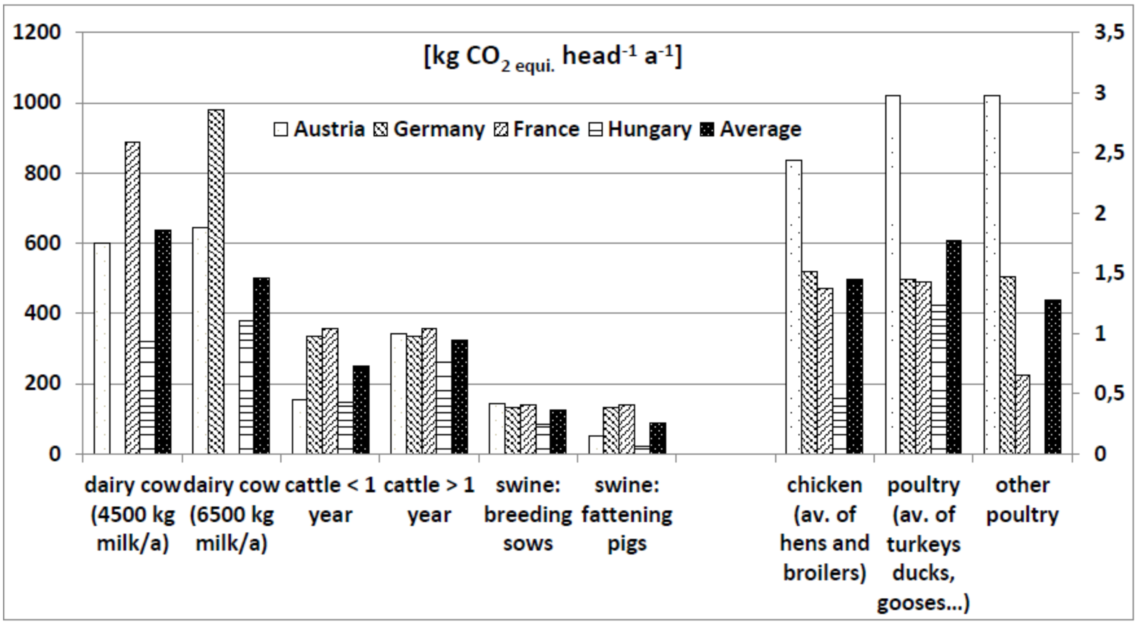

Figure 2: CO_2 equivalent emissions from slurry tanks per animal and year (considered:CH_4 and N_2O) expressed in kg $CO_{2equi.}$ per head and year; © Kirchmeyr 2016.

Instead of storing the farm fertilizer untreated in slurry tanks, it can be digested in biogas plants and used for renewable energy production. Figure 3 gives an overview of possible energy yield from farm fertilizer based on the amount of volatile solids (Figure 1) within the farm fertilizer.

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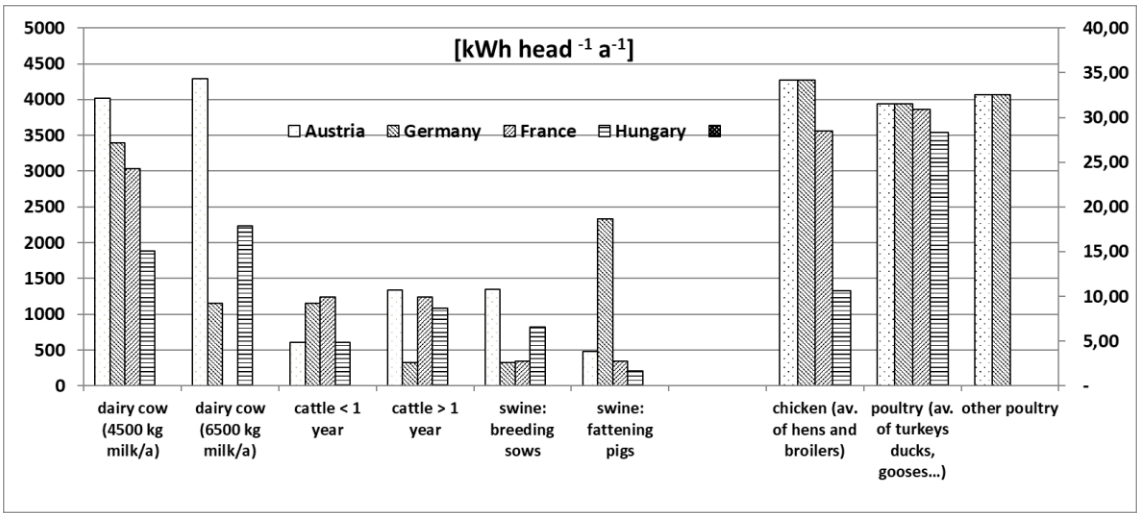

Figure 3: Possible energy yield from excrements of husbandry via anaerobic digestion expressed in kWh head^{-1} a^{-1}; © Kirchmeyr 2016.

Due to the above-mentioned effect that untreated stored farm fertilizer causes GHG emissions whereas the digestion of this farm fertilizer produces renewable energy, digestion of farm fertilizer even entails negative emissions compared to fossil fuel.

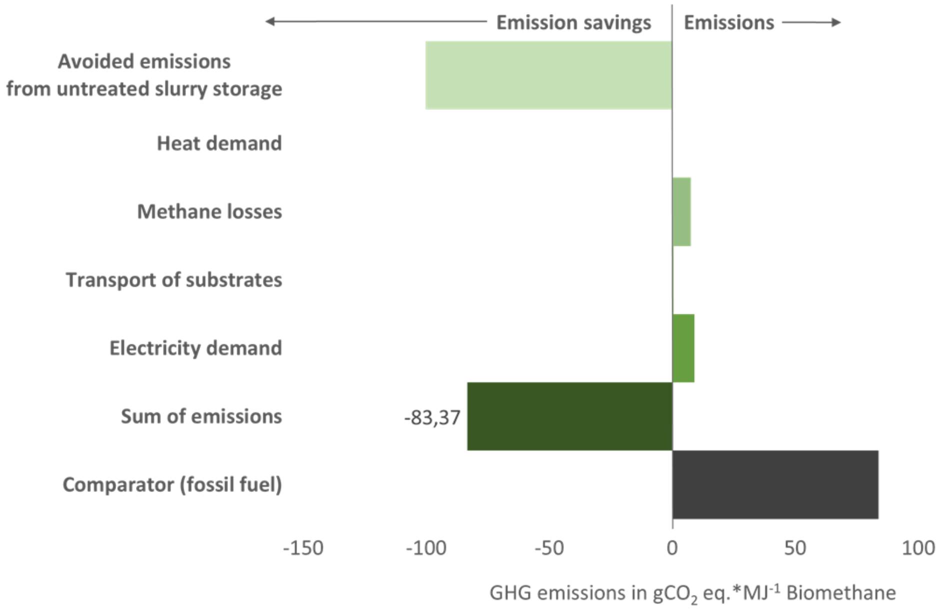

Figure 4: Sum of emissions of biomethane production from farm fertilizer compared to fossil fuel comparator of RED II expressed in g CO_{2eui} MJ^{-1}; © Mayer S. et al. 2016.

1.1.2 Treatment of straw and other agricultural residues

As already shown in the chapter about digestate storage and use, the treatment of straw and second crops offers benefits to agriculture without negative effects on humus and soil microorganism content. Compared to the use of fossil fuel, it additionally offers a great benefit on behalf of greenhouse gas emissions.

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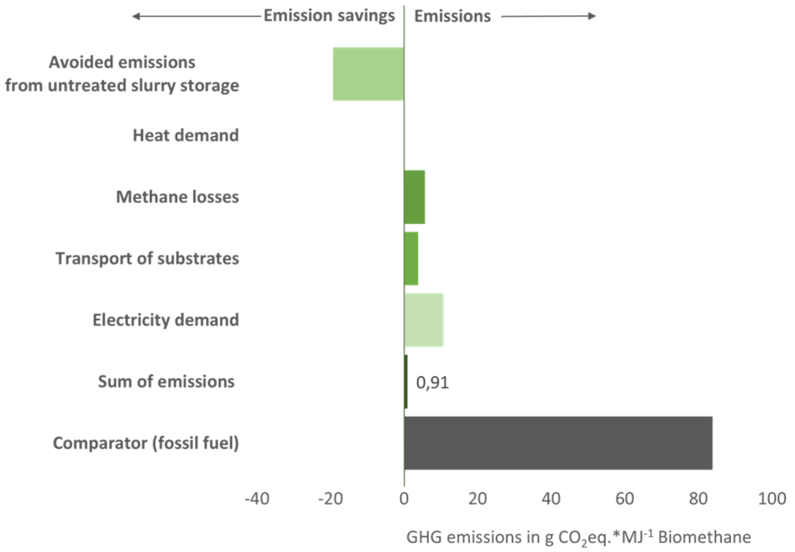

Figure 5: Sum of emissions of biomethane production from farm fertilizer and straw compared to fossil fuel comparator of RED II expressed in g CO_{2eui} MJ^{-1}; © Mayer S. et al. 2016.

1.1.3 Treatment of organic waste

While farm fertilizer and straw are typical agricultural substrates that usually stay in the agricultural circle, anaerobic digestion of biowaste offers the additional advantage to bring back nutrients for plant nutrition and replaces mineral fertilizer. Table 2 shows the average content of macro nutrients within bio waste from separate collection of organic waste from households.

Table 2: Main nutrient content of bio waste; © Kirchmeyr 2016.

Average main nutrient content of bio waste		
[kg N t_{FM}^{-1}]	[kg P_2O_5 t_{FM}^{-1}]	[kg K_2O t_{FM}^{-1}]
6.9	1.95	5.5

Although nutrient recovery and especially phosphorus recycling will be a very important issue in the future, the most important driver for reducing emissions of digesting organic waste streams are the emissions avoided by landfilling organic waste. Figure 6 shows the emissions avoided when organic waste is not landfilled, the emission credits for renewable energy production as well as the emission credits for recycling nutrients. If landfilling of organic waste is banned and thus the emissions of landfilling don´t need to be considered anymore, the GHG mitigation would be 80 % compared to fossil fuel (RED II).

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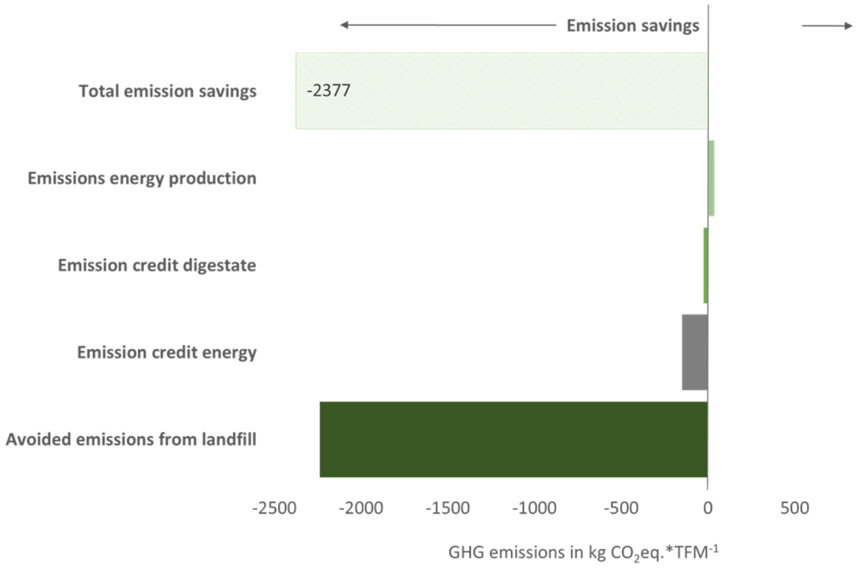

Figure 6: Emissions of biomethane production from separately collected municipal organic waste expressed in $CO_{2equi.}$ t_{FM}^{-1}; © Mayer 2016.

1.2 Application via Combined Heat & Power (CHP)

So far, biogas in Europe is most commonly used to produce electricity & heat in combined heat & power devices (CHP) directly at the biogas plant. The application to produce electricity from biogas can be done in micro gas turbines, Stirling engines, internal combustion engines or within fuel cells. Each application technique has its own special requirements for the use of biogas. To avoid damage to the application technique it is therefore necessary to check the manufacturers handbook on their special requirement. As CHP units are the most common technique for electricity production the further explanations focus on this technology.

To avoid damage to the internal combustion engine, biogas needs to be purified from possible impurities. These impurities and their amount depend, besides water vapor, mostly on the used feedstock. Possible impurities are (besides others):

- Hydrogen sulphide
- Water
- Siloxane

As sulphur is an essential nutrient of all living species, it is transported into the biogas plant with the feedstock and is partly converted to H_2S in the digester. Sulphur molecules, like H_2S cause corrosion. Each manufacturer of engines prescribes an upper limit for hydrogen sulfide. The concentration of hydrogen sulfide within raw biogas depends much on the sulphur content of the feedstock. Typical concentrations can be in a range of below 100 up to some thousand ppm. H_2S can be reduced by several desulphurization techniques, like biological conversion, chemical or physical treatment of raw biogas. The technology applied depends on the biogas plant´s design and on the used feedstock. If feedstock is used with relatively low sulphur content, biological treatment within the gas space of the digester is a very cost-efficient technique and therefore often used. Here, the bacteria Sulfobacter oxydans converts hydrogen sulfide at the presence of oxygen to elementary sulphur. The installation of equipment is simple: Just a blower that blows some air into the top of the digester is needed. Additionally, the bacteria need all other nutrient for living (given inside a digester) and a place to settle.

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Some digesters are constructed in a way to offer enough surface for those bacteria to settle. This process can also be done in external desulphurization devices. These airtight towers are filled with parts where bacteria can settle, and a nutrient solution will be spread from above to provide needed nutrients and to wash down produced elementary sulphur. Biogas is blown through such a desulphurization tower from the bottom up. A different kind of installation is chemical desulphurization. It is mostly done through adding iron compounds (iron III chloride, iron II chloride, etc.). Iron compounds fed into the liquid digester content will bind the Sulphur within digestion liquid. Chemically bonded sulphur cannot be released into the biogas. The third commonly used method is the adsorption on activated carbon. This method is typically used (often in combination with other methods) if biogas is upgraded to biomethane and needs to fulfil very low and strict upper limit values. The hydrogen sulphur is adsorbed on specially conditioned activated coal.

Biogas is saturated with water vapor and therefore it starts to condense the moment the biogas temperature is lowered, e.g. in the pipes behind the digester. To avoid water at the entry to the engine, most plants cool the biogas through pipes underneath the surface or through a water cooler. Important is that the condensate needs to be collected at the lowest point of the pipes and discharged in a condensate trap. As the biogas is still saturated with water vapor after cooling, it is important to heat the biogas up so the relative humidity is below 100 %. This is mostly done with exhaust heat from the blower and with a security electric heating system.

Siloxane only occurs if biogas is produced from sewage sludge or special foam preventing agents are applied to the digester. Siloxane might cause deposits on the spark, the injection valves, the exhaust valves and on the surface of the piston. This could cause damage to the engine. Most plants using sewage sludge install a security step in form of an activated coal filter so that possible siloxane can be removed in case it occurs.

Picture 1: Left: blower for desulhuration with air, middle: elementary sulphur within a gas pipe, right: sulphur at the top of the digester.

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Picture 2: Left: external desulphurization column, middle: padding material for sulfobacter oxydans within external desulphurization column, right: activated coal filter.

Figure 7: External biogas coolers with integrated particle separator.

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According to the Paris Agreement, the energy production shall be switched completely to renewable energy sources in order to combat climate change.

The electricity production from biogas offers many advantages: it is very reliable, storable, can be applied flexibly and offers the highest full load hours within all renewable electricity productions. A forecast scenario of future electricity production shows the very volatile production from non-biomass driven renewable electricity sources. With biogas, the production can be adjusted exactly to the current demand with peak load production and even control energy production so that the electricity grid is stable with a high security of supply.

Table 3: Full load hours of Austrian Biogas plants in 2018; n= 177; © BMNT 2018.

		Best 25 %	Average of all plants	worst 25 %
Full load hours	[h a^{-1}]	7 374	7 350	6 174

Table 3 shows typical full load hours of biogas plants. In comparison, solar and wind power are fluctuating. As in the future, electricity should only come from renewables and here mainly from fluctuating sources, the security of supply will become a major issue and energy systems must provide electricity even when the sun is not shining, and wind is not blowing. Biogas can be stored in case there is enough electricity from wind and sun and can be used instead in times when electricity is needed.

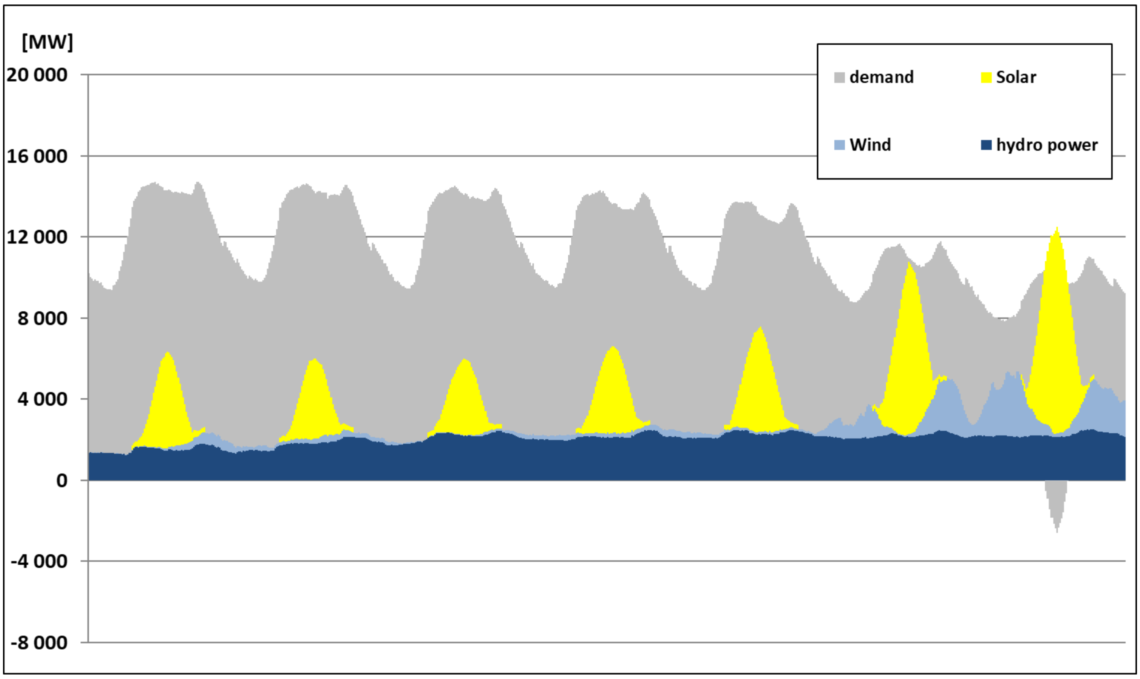

Figure 8: Forecast of Austrian electricity demand and supply from volatile renewables in week 6 of 2030; © Stürmer 2018.

Another common practice is to use CHPs for off-grid electricity production. Here, biogas can also be a good renewable source. For off-grid electricity production, the situation is like the one described above: electricity must be produced even in case the sun and wind do not provide enough energy. In practice usually an engine that is driven by diesel is installed. Biogas offers the advantage that the fuel needed for the engine can be produced with locally available

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resources. Additionally, a CHP driven by biogas can deliver electricity reliably which is often not the case in many areas around the world. There are biogas installations that were mainly constructed to avoid blackouts in the electricity grid.

The electrical efficiency of a CHP unit depends on its size and could be raised within the last two decades. Currently, the electric efficiency of a mid-size CHP is around 40%, larger units even reach an electric efficiency of the whole unit above 43%. Engines for CHP can be only driven by biogas. In this case, the ignition is done by a spark. Also, dual fuel engines are used. The ignition of the injected biogas is done by a liquid fuel which is usually around 5% of the total energy demand. The ignition fuel can be diesel or biofuel. Due to restrictions using fossil fuel as ignition fuel, the ignition fuel is typically a biofuel. The mostly used engines are single fuel engines that operate as gas-otto-engine. To produce electricity, the gas engine is coupled with a synchronous or asynchronous generator. Synchrony generators offer the opportunity that they can also produce electricity without the impulse from the electricity grid. Asynchronous generators are only used in CHP below 100 kW_{el}. As the temperature of the surrounding air has an important influence on the electric efficiency (besides other) it is important to steer the cooling air directly to the generator followed by the engine.

A gas engine must be cooled. This is typically done with a water-cooling system. As this cooling water is warmed up typically to about 90-95°C, this heat can be used, for example to heat up the digester but for many other purposes as well. Typically, this heat is used for heating houses, drying crops or wood, glasshouses or in industrial processes where heat is needed. In addition to the heat from the cooling cycle, the heat from the exhaust can be used through an external heat exchanger.

The total efficiency of the biogas plant, especially of the gas engine is depending highly on the use of the heat because the electric efficiency is around 40% and the thermal efficiency is often higher than that. More energy is transferred to heat than to electricity. An efficient biogas plant should always be equipped to use the thermal energy.

It is important to follow the manufacturer´s instruction on minimum temperature of exhaust gas after the heat exchanger in order to avoid corrosion and sediments and thus damage of the heat exchanger). New CHP installations run closely to 90% of total efficiency (electricity plus thermal energy). With a special heat exchanger; also steam production is possible. Corrosion of the CHP due to impurities within the biogas is an aspect to avoid, but the coolant liquid also needs to be considered. Using only fresh water is not allowed by most of the CHP manufacturers. It needs to be desalinated and additives need to be added.

To avoid unwanted emissions, CHPs must be checked periodically and must fulfill strict emission limits. CHPs have their own measurement and steering installed in order to reach a high performance and to fulfill the requirements of upper limiting values for emissions.

Table 4: Upper limit values for new CHPs above 1 MW_{th} input using renewable gases referred to 273.15 °K, 101.3 kPa and standardized oxygen content in the off gas of 15 % ; © 2015/2193/EU.

Pollutant	[mg Nm^{-3}]
Sulphur dioxide [SO_2]	40
Nitrogen oxide [NO_x]	190
Dust	-

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Table 5: Upper limit values for new CHP´s using biogas referred to 273.15 °K, 101.3 kPa and standardized oxygen content in the off gas of 5 % ; © Technische Grundlage für die Errichtung von Biogasanlagen. BMWFW 2017

Pollutant	**[mg Nm^{-3}]**	
	< 250 $kW_{th.}$	250 – 1 000 $kW_{th.}$
Sulphur dioxide [SO_2]	-	310
Nitrogen oxide [NO_x]	1,000	500
Carbon monoxide [CO]	1,000	650
Formaldehyde [HCHO]	60	60
Dust	-	-
For bigger combustion plants EU directive 2015/2193 is applicable.		

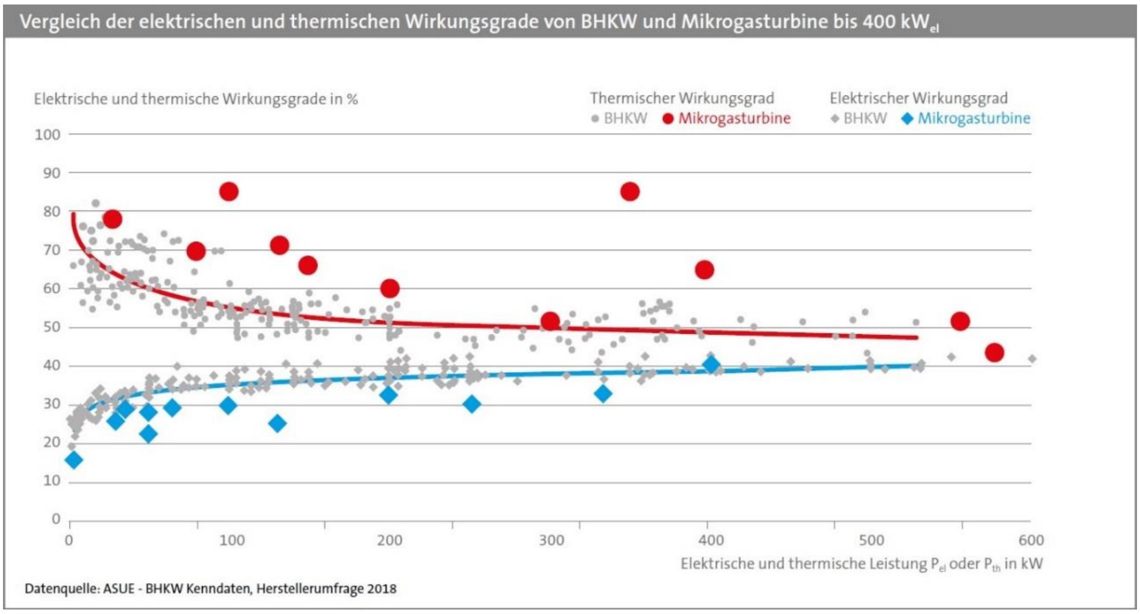

Figure 9: Comparison of total, electric and thermal efficiency of CHP and micro gas turbines depending on installed electrical capacity; © ASUE 2018.

The efficiency of a CHP unit is depending highly on the size. The bigger the size, the higher the electrical efficiency but the lower the thermal efficiency. The grey dots in Figure 36 show results from measurements of gas engines. The red line shows the average thermal efficiency. The blue line the electric efficiency. Red and blue dots are from measurements of micro turbines.

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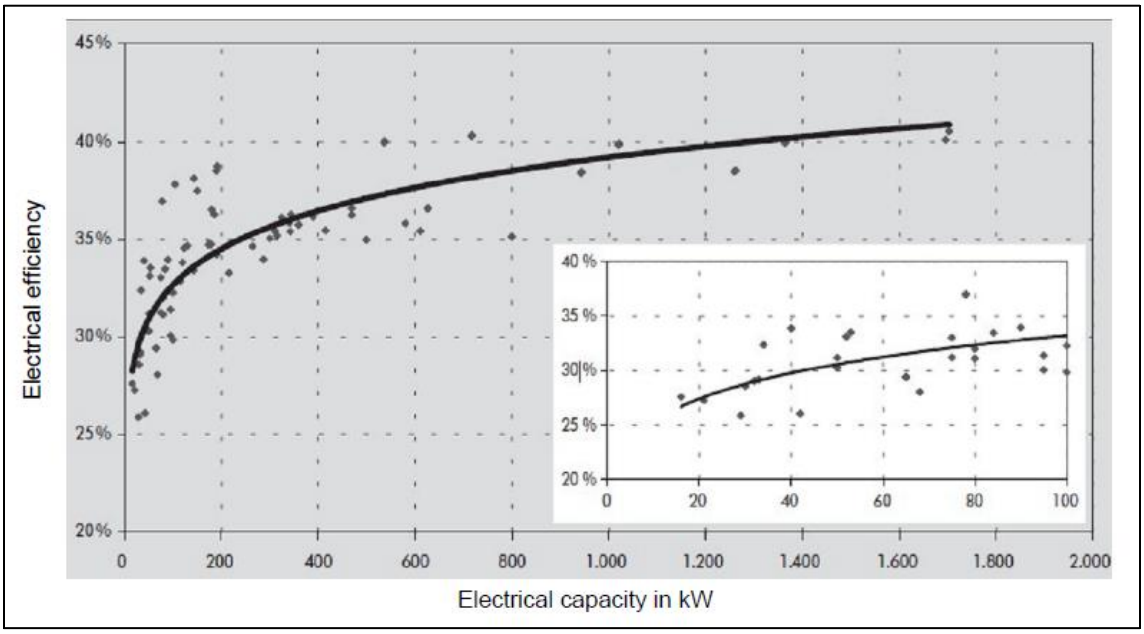

Figure 10: Electric efficiency of various CHP´s; © Biogas guide book 2019.

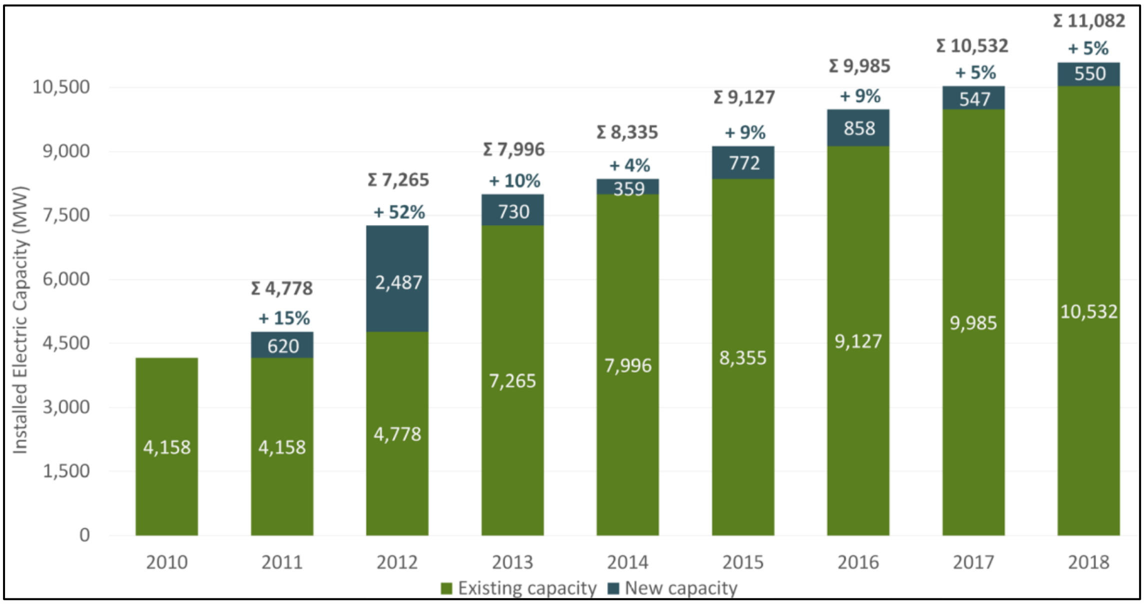

Figure 11: Development of installed electric capacity of biogas plants in Europe expressed in $MW_{el.}$; © EBA 2020.

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Picture 3: CHP unit: left: steered intake air, steering, generator, heat exchanger and gas engine, right: fully equiped CHP container with cooling, flare, heat exchanger and exhaust pipe above the container.

1.3 Boiler/Cooking

In some cases, the direct heat utilization is an option for biogas. Within Europe, this is not applied very often because electricity has a much higher value and can be used more flexibly than heat.

However, if heat can be used, this is mainly done to produce process heat in the industry, steam, peak load and failure reserve heat for district heating systems. If the district heating system is managed by a biogas plant, the base load for the heat supply mainly comes from the CHP unit of the biogas plant.

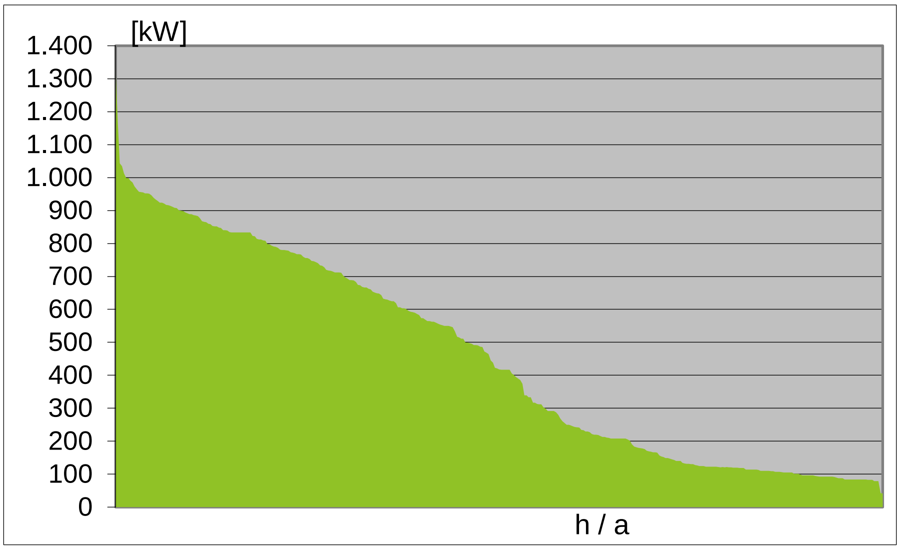

Figure 12: Typical heat demand curve in a local district heating system © AKBOE 2012.

Figure 12 shows that the heat demand usually varies greatly throughout the year. Peak loads (left) are only needed for some hours per year, while the base load is almost always needed.

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Picture 4: Typical peak load boiler for biogas with a capacity of 7.2 MW_{th}.

1.4 Upgrading biogas to biomethane quality

Biogas consists of methane, carbon dioxide and some minor components. If it is cleaned, minor components are eliminated, and methane is separated from carbon dioxide, almost pure biomethane can be achieved. For comparison, methane is the main component of natural gas which contains typically between 90 to 97% methane.

Upgrading units purify the biogas typically up to 90-99% methane content, fulfilling the requirements of natural gas. This offers an additional wide range of applications like:

- Direct use as transport fuel
- Gas grid injection and following applications
  - Transportation
  - Heating & cooking
  - Combined heat & power

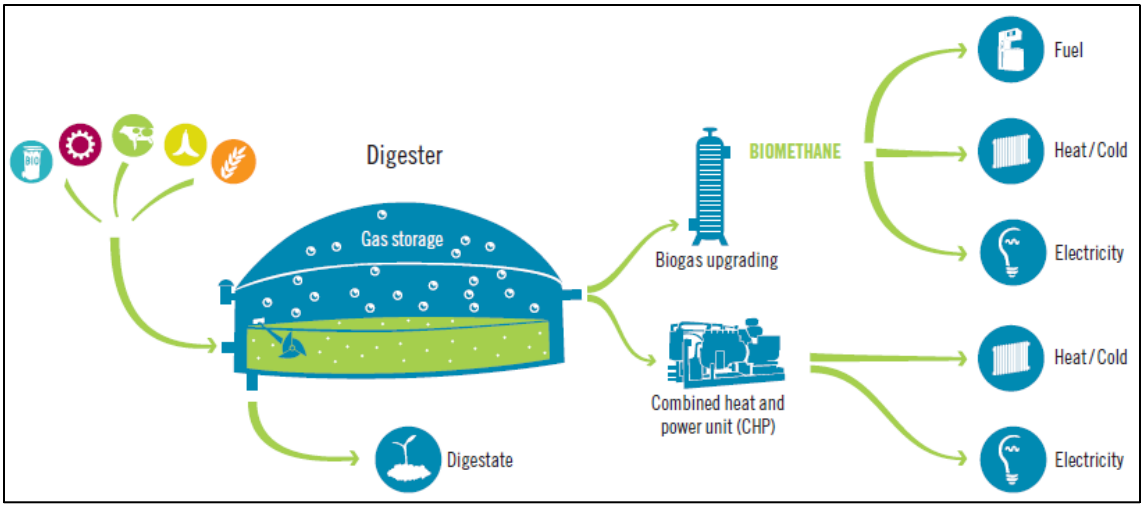

Figure 13: Process of biogas production and its possible applications; © Fachverband Biogas 2017.

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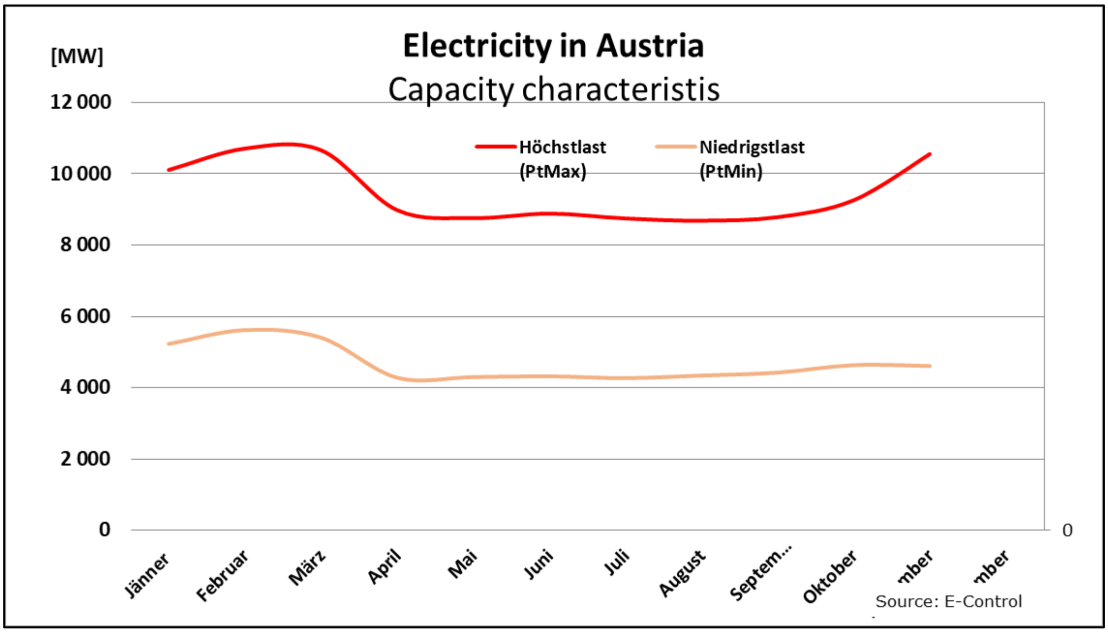
In Europe, two main grids for transportation of energy are available, the electricity and the gas grid. Both grids play a key role in delivering energy to consumers, for the security of supply and both have their own specifications. These characteristics will be explained based on data from Austria. In 2018 energy demand delivered through the gas grid reached 90.7 TWh compared to the electricity grid with 66.4 TWh. While the electricity grid reaches a peak load of around 11 $GW_{el.}$ the gas grid exceeds this value nearly threefold to around 28 GW_{th}. At least due to its topographic conditions Austria has a very high amount of installed hydro pump storage with a total storage capacity of 3.3 $TWh_{el.}$ and with a max. performance of 6.4 GW_{el}. In comparison the Austrian gas system has a cavern storage capacity of 91.8 $TWh_{th.}$ in total and a performance of 44.6 GW_{th} (E Control 2019). For the latter, the most important point is probably not only the max. storage capacity but also the possible maximum performance at times where the demand is usually very high, and the actual stored energy is at its lowest point. These points usually happen in the first two months of the year where low temperatures cause high energy demand and on the other side hydro power from river runs off and wind and PV are sometimes at the lowest level. Figure 15: Maximum available capacity of pump hydro storage compared to gas storage within caverns per week; © ENTSO E, E-Control shows these points for both grids. While pump hydro storage can secure security of supply for about 3 days, the gas storage systems allow to secure supply for more than 20 days. These figures bring new facts to light and highlight the importance of the gas grid.



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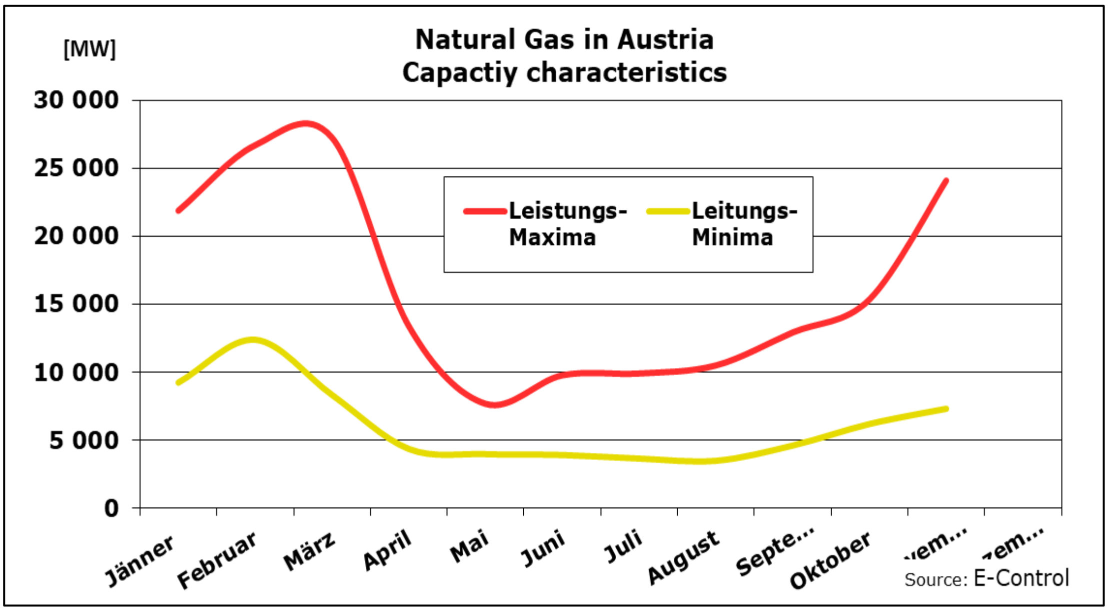
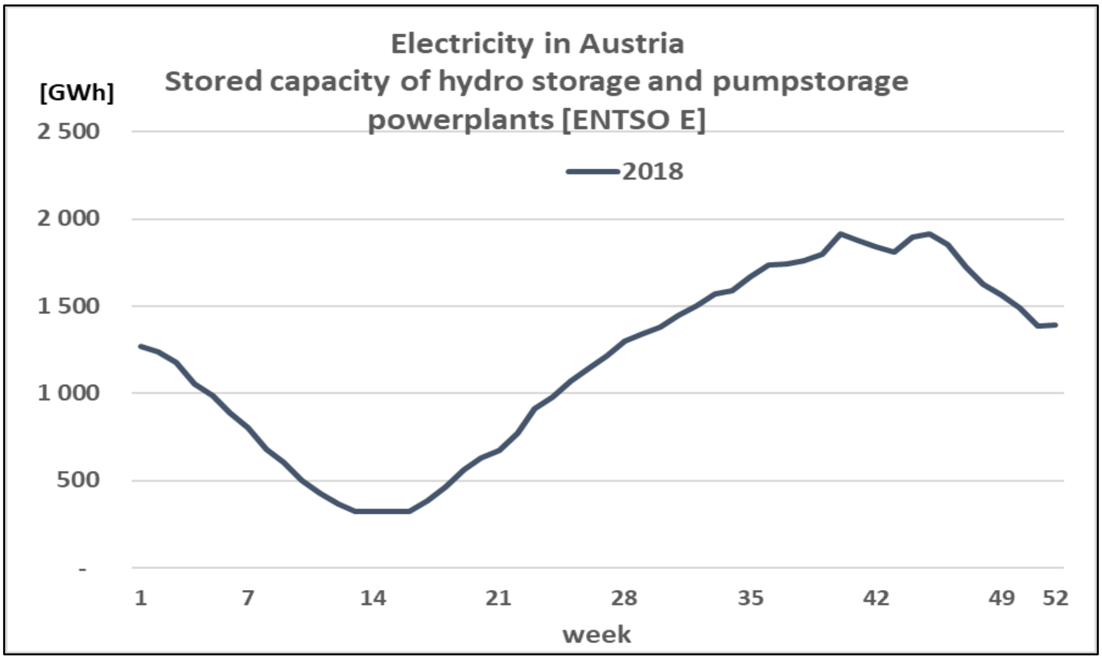


Figure 14: Maximum and minimum load of Austrian electricity grid compared to the gas grid; © E Contro 2018



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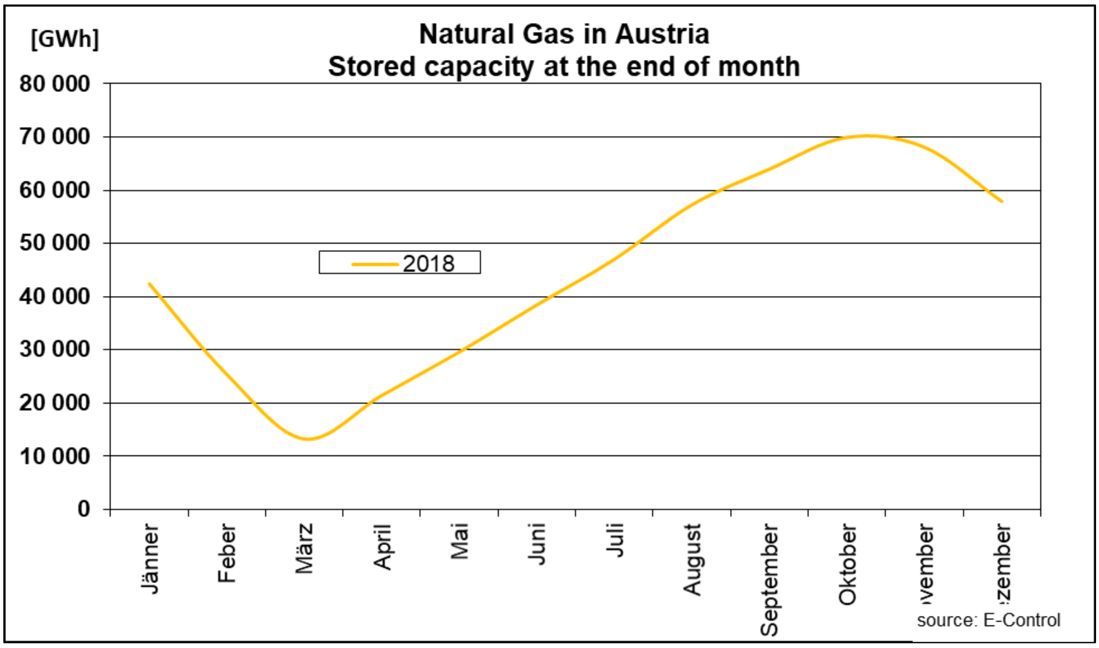

Figure 15: Maximum available capacity of pump hydro storage compared to gas storage within caverns per week; © ENTSO E, E-Control 2018

Natural gas is a fossil fuel. If it is burned, additional GHG is released. In the light of the Paris Agreement, also the gas grids need to switch to renewable energy. The predominant and most promising technique to achieve this is upgrading biogas to biomethane.

Before biogas can be injected into the gas grid, biogas needs to be purified from possible components which are not allowed to be injected into the gas grid. These components are mainly the water content, several components of Sulfur and Nitrogen, Oxygen and at least Siloxane etc. Additionally, the required caloric value and Wobbe Index need to be adjusted through elimination of carbon dioxide. Table 6 shows typical components within biogas and the requirements for gas grid injection.

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Table 6: Components of raw biogas versus requirements for gas grid injection within Austria; © ÖVGW G31 and GB220.

Component		Biogas [$\%_{vol.}$]	Requirements for gas grid injection in Austria	
			ÖVGW G 31	*ÖVGW GB 220*
Methane	[CH_4]	50 – 70		≥ 96 $\%_{mol}$
Carbon dioxide	[CO_2]	30 - 50	≤ 2 $\%_{mol}$	
Higher heating value				≥ 10.7 kWh_{Hs} Nm^{-3}
Wobbe Index			≥ 13.3 kWh_{Hs} Nm^{-3}	
Nitrogen	[N_2]	0 - 5	≤ 5 $\%_{mol}$	
Sulfur (total)	[S]		≤ 10 mg m-3	
Hydrogen Sulfide	[H_2S]	0 - 2	≤ 5 mg m^{-3} short term up to 30	
Hydrogen	[H_2]	0 - 1	≤ 4 $\%_{mol}$	
Oxygen	[O_2]	0 - 1	≤ 0.5 $\%_{mol}$	
Ammonia	[NH_3]	0 - 2	0	
Dew point		saturated	≤ -8 at 40 bar	
Siloxane				≤ 5 mg m^{-3}

Due to their components and density, different gases have a different flow speed, caloric value etc. and therefore different properties. For gas devices the Wobbe Index is, besides the caloric value of the gas, an important characteristic quantity. It expresses the convertibility of different gases so that those can be applied with the same gas burner without changing the burner nozzle. The Wobbe Index is calculated by dividing the higher heating value with the radical of the relative density between gas and air:

$$Ws = \frac{Hs}{\sqrt{\frac{gas\ density}{air\ density}}}$$

Therefore, each burning device has the *Wobbe* Index included on its labelling.

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Table 7: Typical Components within biomethane and their impact on the Wobbe Index; © AKBOE 2020

Components		[%]				
Methane	[CH_4]	**90**	**92**	**94**	**96**	**98**
Carbon dioxide	[CO_2]	8,17	6,17	4,17	2,17	1,17
Nitrogen	[N_2]	1,5	1,5	1,5	1,5	0,5
Oxygen	[O_2]	0,03	0,03	0,03	0,03	0,03
Hydrogen	[H_2]	0,3	0,3	0,3	0,3	0,3
Hydrogen Sulfide	[H_2S]	0	0	0	0	0
total		100	100	100	100	100
Wobbe Index	**[kWh_{Hs} Nm^{-3}]**	**12,5**	**12,9**	**13,4**	**13,9**	**14,4**
	[MJ_{Hs} Nm^{-3}]	**44,9**	**46,6**	**48,4**	**50,2**	**51,9**

1.4.1 Purification

Purification of biogas usually includes desulphurization, drying and separation of carbon dioxide.

1.4.1.1 Desulphurization

The content of hydrogen sulfide within the biogas depends on the used feedstock. Hydrogen sulfide itself has corrosive properties. Additionally, it will be converted through combustion to sulfide dioxide which accumulates on sensitive components and is an environmental pollutant causing acid rainfall. Usually H_2S occurs in biogas at a higher concentration than the upper limit value for gas grid injection. Therefore, it must be reduced. As oxygen, different components of nitrogen and sulfur are limited within biomethane and additionally would lower the caloric value and the Wobbe Index, desulphurization differs between direct CHP application and upgrading to biomethane. Instead of using air for biological desulphurization (air contains mainly nitrogen which should not be present in pure biomethane), pure oxygen is used. Additionally, desulphurization is in most cases done in more than one step. It is often a combination of several steps from the following possibilities:

- Chemically by adding doses of iron salts into the liquid phase of the digester
- Biological desulphurization with oxygen in an external column
- Adsorption on activated carbon

1.4.1.2 Drying

At its formation, biogas is saturated with water vapor and reaches the dew point at each point it is cooled, and water will occur. The appearance of water within the gas grid needs to be avoided because it could be accumulated at the lowest point of the gas grid and cause pressure variation. Additionally, it could cause damage to application devices like an internal combustion engine. Different dewatering techniques are used to fulfill the requirements like:

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- Condensation through cooling
- Adsorption with zeolites, silica gels or aluminum oxide
- Absorption with glycol

The most common technique for dewatering the biogas is cooling with a cooling aggregate. Additionally, the carbon dioxide removal step like pressure swing adsorption also removes water. This can be considered as a security step. Adsorption with zeolites, silica gel or aluminum oxide is done in two alternately pressure vessels.

1.4.1.3 Carbon dioxide removal

Carbon dioxide removal is the necessary step to reach the minimum level of caloric value and Wobbe Index for gas grid injection. Choosing the right technique depends on several parameters such as the required methane content, energy demand, required gas grid pressure, existence of waste water, maximum methane losses etc. The most commonly used techniques for Carbon dioxide removal are:

- Pressure swing absorption
- Water scrubber
- Chemical absorbance
- Membrane technique

1.4.1.3.1 Pressure Swing Adsorption (PSA)

Pressure swing adsorption is a proven method of separation and has been applied for decades. It is used in the gas industry, and was adapted to the requirements of biogas processing.

The essential component for separating the gases is a column filled with activated carbon, zeolitic molecular sieves or carbon molecular sieves. These substances have excellent characteristics such as a large surface area and a certain pore size. Usually at least two columns work directly together. To reach a continous process always at least 4 up to 8 columns are installed in a PSA device.

When biogas is fed into the first PSA column, the activated carbon physically adsorbes CO_2 while methane passes the process. The moment the activated carbon has reached full load with carbon dioxid the raw biogas inlet will be closed and led to another parallelly installed vessel also filled with activated carbon. Removing carbon dioxide from the acitivated carbon is done by directing the gaseous content to another gaseous empty vessel with activated carbon until both vessels have reached nearly the same pressure. The last step of emptying the carbon dioxid loaded vessels is done with a vacuum and the vessel is again ready for removing carbon dioxide from raw biogas. These connected steps are necessary to reach high contents of methane in the purified biomethane, to guarantee low methane losses and to avoid unwanted high energy demand. Therefore, at least four vessels are involved to reach a continous process. A positive effect of the process is that the remaining and unwanted gases like H_2S are also kept by activated carbon and it finally dries the gas. At the moment H_2S passes the process, the activated carbon needs to be maintained or changed. In order to avoid that the lifetime of the activated carbon is too low, fine-cleaning must be carried out to remove the H_2S before the biogas is pumped into the adsorption column.

The methane losses are mainly dependent on the design of the system. The CH_4 in the exhaust gas must be burnt because of its greenhouse gas relevance.

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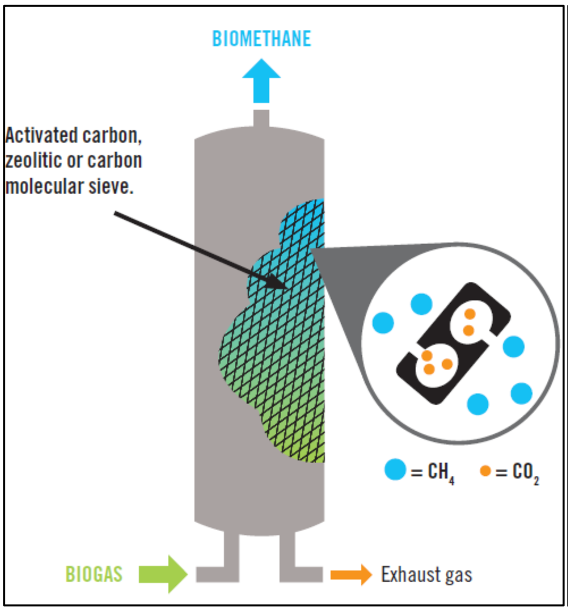

Figure 16: Left: Detail of a CO_2 separation vessel with activated carbon in a Pressure Swing Adsorption device (PSA); © Fachverband Biogas 2017, right: PSA column.

1.4.1.3.2 Water scrubbing

We all know this effect in our sparkling beverages: in the cold and under light pressure carbon dioxide is soluble within the fluid. By releasing pressure, for example by opening the beverage bottle, carbon dioxide is released. Heating the fluid up lowers the solubility of carbon dioxide additionally. Water scrubbing uses this well-known effect of different solubility of carbon dioxide and methane within water. In a first step biogas is cleaned from water droplets and other bigger impurities, then flows pressurized with 4 up to 10 bars into the scrubber column at the bottom while in counterflow cold water flows from top to bottom. Carbon dioxide, hydrogen Sulphur, ammonia and particulates are dissolved in the water and at the top of the column methane rich biomethane can be extracted. For gas grid injection the biomethane again needs to be dried. At the bottom of the column carbon dioxide rich water with low content of methane is led to the flashing tower. In order to keep the dissolved methane within the process the pressure is removed as a first step, and dissolved methane escapes from the water and is directed into the process again. In a second step the exhaust gas rich water is directed into the flashing tower where in counterflow the CO_2 etc. is released into the air by lowering the pressure to ambient air pressure and air is pressed inside from the bottom. If the hydrogen Sulphur content is not too high within biogas and because H_2S dissolves very well in water, water scrubbing usually reaches the requirements for the upper limit value of H_2S for a gas grid injection without any further treatment. Depending on the methane content in the exhaust gas an additional post-combustion step is needed.

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Table 8: Solubility of different gases at 1 bar and different temperatures within water; © Tretter H. 2003.

Component		Solubility in water at 1 bar partial pressure of dissolved gas [mmol/kg bar]	
		0 °C	25 °C
Methane	[CH_4]	2.45	0.72
Carbon dioxide	[CO_2]	75	34
Ammonia	[NH_3]	53,000	28,000
Hydrogen Sulfide	[H_2S]	205	102
Air		1.27	0.72

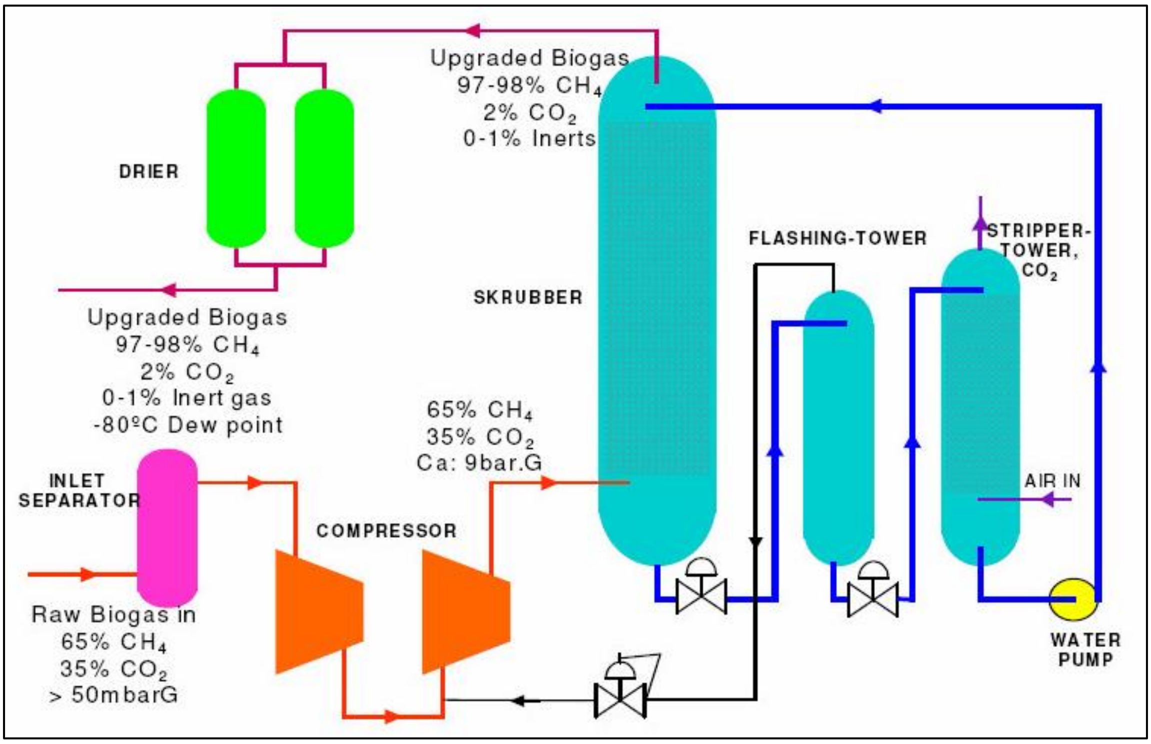

Figure 17: Scheme of water scrubbing technique; © Tretter H. 2003.

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Picture 5: CO_2 separation through water scrubber left: scrubber column, right: water scrubber technique installed in a container

1.4.1.3.3 Physical scrubbing

Carbon dioxide removal through physical scrubbing is also based on the different solubility of gases within fluids. The process is very similar to water scrubbing with the main difference of the solvent. Using a special solvent, Polyethylene glycol (brand: Selexol) has the advantage of a higher solubility of gases like CO_2. Therefore, for this process less pressure and smaller columns are needed for the same performance compared to water scrubber. The downside is that it is more difficult to regenerate the solvent. Usually heat is needed to separate CO_2 from the solvent after the scrubbing process.

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Figure 18: CO_2 separation through physical scrubber, left: scrubber column, right: physical scrubber installed in a container

1.4.1.3.4 Chemical Scrubbing

Chemical scrubbing is similar to the process of physical scrubbing. The main difference between physical scrubbing and chemical scrubbing technologies is that for the latter the affinity to CO_2 is even higher. The consequence is a very high selectivity of the process. The purity of the gases is very high, e.g. above 99.9% methane concentration and less than 0.5% methane losses are possible. Another advantage is that the scrubbing columns can be operated at atmospheric pressure, while all other biogas upgrading technologies are operated with pressurized columns. The disadvantage is that the recovery of the detergent needs to be done with heat. For the latter it is good to have exhaust heat nearby. Used chemicals are Monoethanolamine (MEA), methyldiethanolamine (DEA) etc.

1.4.1.3.5 Membrane technique

Membrane technique uses the different permeability and size of various gaseous molecules to differ through special conditioned membranes. The permeability of membranes for CO_2 is 20 times higher than the one for CH_4. The hollow fibres itself are bundled together in a steel column. Depending on the needed performance several columns work in parallel.

To reach a high methane content in the produced gas and to avoid an excessive loss of methane within the exhaust gas, the membrane technique is usually applied in a two or three stage process. As nitrogen does not diffuse through the membrane wall either and stays in the produced gas together with the methane, it is important to avoid any accumulation of nitrogen within the biogas. To avoid damaging the membranes too quickly, biogas needs to be dewatered, de-oiled and desulfurized very well before entering the membranes.

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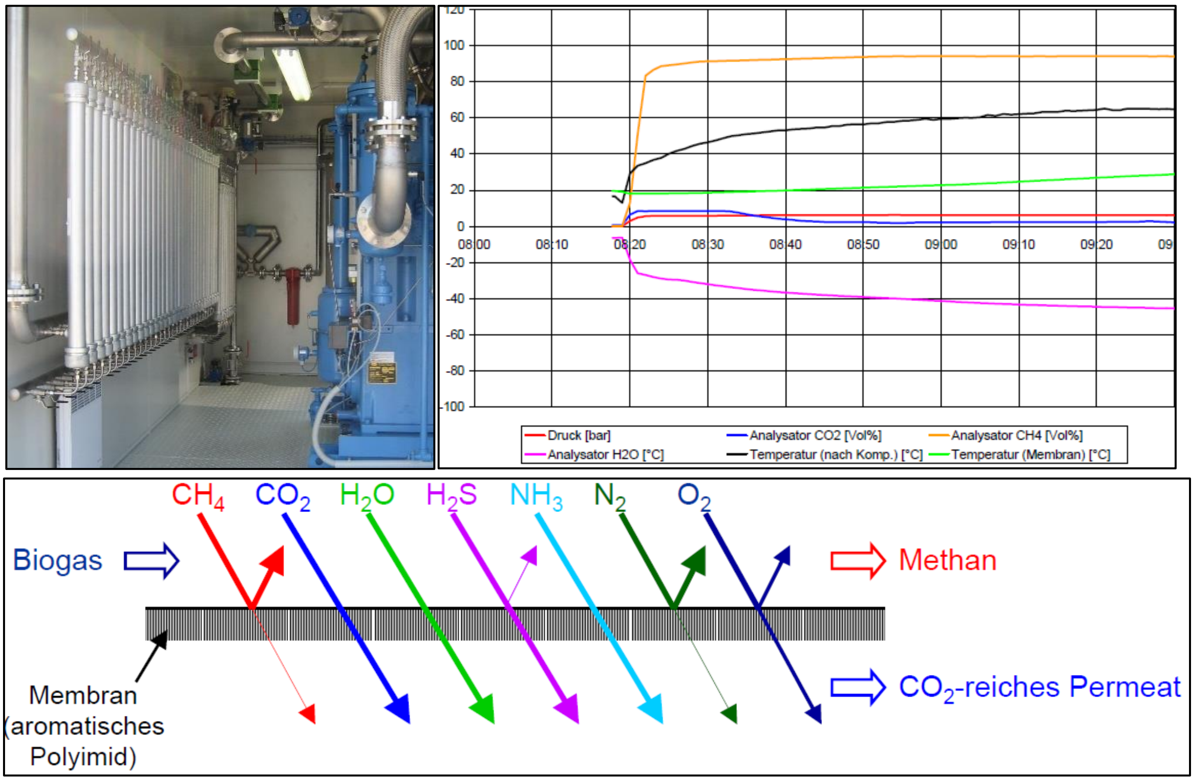

Figure 19: Top left: CO_2 separation through membrane technique, top right: ramp up curve after start, bottom scheme of membrane technique; © top right & bottom: © Harasek, 2009.

The choice of upgrading technique depends on several factors such as:

- Plant size
- Required pressure after purification
- Upper limit of methane content in the off gas
- Availability of waste heat
- Availability of waste water
- Availability of maintenance companies

During the last two decades, upgrading techniques underwent huge developments and the installed techniques changed according to special conditions and the regional situation of the biogas plant but also based on the technical development and legal requirements. About 500 industrial installations are upgrading biogas to biomethane today. Many experiences with this technology have been gained throughout the last 20 years. Thus, we can conclude that upgrading biogas is the state-of-the-art and an approved technology.

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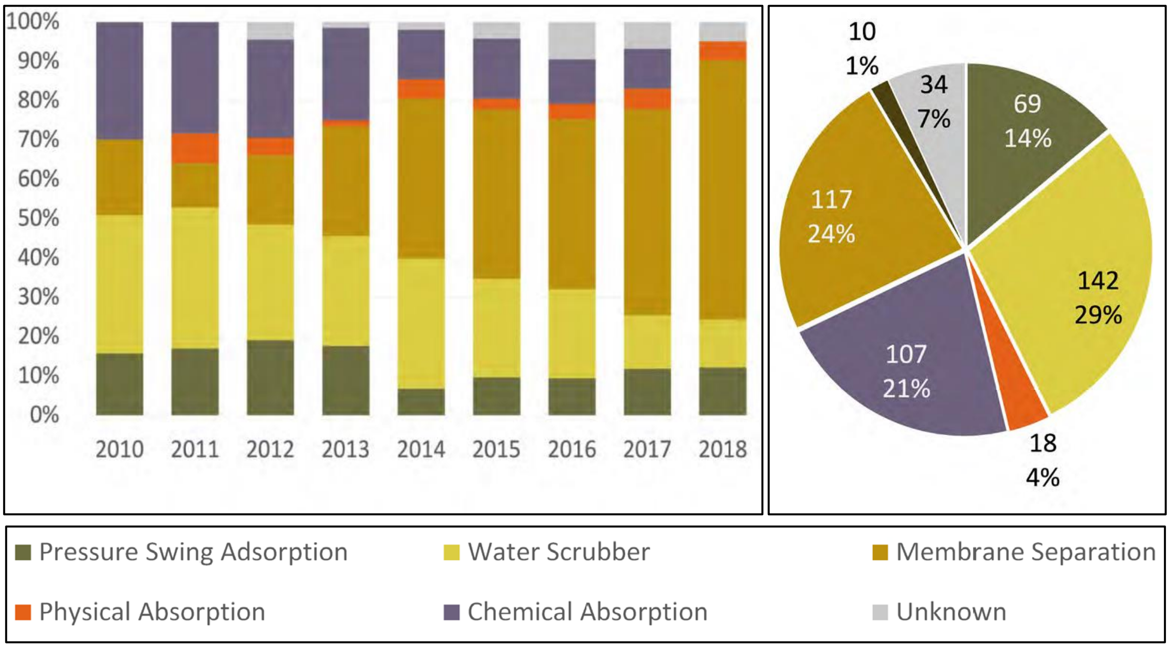

Figure 20: Relative use of upgrading techniques, left: worldwide, right: Europe; © EBA, DMT 2020.

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The DiBiCoo Consortium

COORDINATOR

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

PARTNERS FROM EXPORTING COUNTRIES

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Project website: www.dibicoo.org

Project Coordinator Contact

Dr. Johannes Anhorn
Deutsche Gesellschaft für
Internationale Zusammenarbeit (GIZ) GmbH

I www.giz.de

Wielinger Straße 52
82340 Feldafing, Germany

T +49 8157 938 0
E johannes.anhorn@giz.de

Author(s)
Franz Kirchmeyr & Bernhard Stürmer, Austrian Compost & Biogas Association, Vienna, Austria

Review
Frank Hofmann (FVB), Michael Rohrer (AEA), Mieke Dekorte (EBA), Angela Sainz (EBA), Ann-Kathrin van Laere (GIZ), Dr. Johannes Anhorn (GIZ), Dominik Rutz (WIP), Felix Colmorgen (WIP),

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