Overview and Categorization of European Biogas Technologies

- MCR: Measurement, Control and Regulation Technique -

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DiBiCoo – Digital Global Biogas Cooperation

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Executive Summary of D2.2

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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List of Abbreviations

AD	Anaerobic Digestion
CHP	Combined Heat & Power
D	Deliverable
d	Day
MCR	Measurement, control and regulation technique
ppm	Parts per million
T	Task
SC	Steering Committee
VFA	Volatile fatty acids

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1 MCR: Measurement, Control and Regulation Technique

One of the main facilities for highly efficient biogas processes is the measurement, control and regulation technique (MCR). It is the central unit for biogas plants where all measured data come together, are recorded and checked and which alerts if data values are not within the allowed range. Measured data are usually:

- Weight of feedstock within the feeding system and fed into the digester
- Pumped quantities (from slurry tanks into digester, between digesters and handed over digestate, added liquid additives)
- Level within digesters (sensors are on bottom and on top)
- Temperature within digesters (sensors are at the bottom and close to the surface of the liquid)
- Filling level of the biogas storage tank
- Biogas production, amount, course (m^3 per time unit) and composition (CH_4, CO_2, H_2S, H)
- Actual current consumption of agitators
- Lower explosion limit within rooms where gas pipes are installed
- Self-consumed energy (electricity, heat)
- Produced energy (electricity, heat, biomethane)
- CH_4 and partially H_2S in rooms where biogas might occur.
- Pressure inside the digester

Measuring CH_4 and H_2S in rooms where biogas might occur is usually requested from the permission authority and is therefore obligatory. The other above listed parameters are not always measured in all biogas plants. Usually the bigger a biogas plant is, the more parameters are measured. This is the case because bigger biogas plants have higher investment costs already and thus, the additional investment needed specifically for measurements is low compared to the overall investment.

The measured data is recorded, analyzed and with an interface the data can be stored externally and is usually used for further evaluations. With the MCR unit more and more facilities in a biogas plant are steered automatically. Some devices like the CHP, the biogas upgrading unit, the biogas analysis and the feedstock feeder always have their own process control system to steer their function internally. Via interfaces they are connected to the main MCR technique and can also be steered from there. Additionally, for some devices like the feeder, pumps, agitators etc. it is beneficial to have main steering buttons directly at the device. MCR technique can also have a remote control so that main process parameters and functions can be seen and steered from the outside.

1.1 Measurement of process parameter

As anaerobic digestion is a biological process, steering an effective process that operates almost at the limit is challenging. Several research programs were carried out to determine absolute characteristics and limit values for a proper process. Measuring the pH value would be easy, but takes some time and hence, does not give feedback about process disturbances early enough. Each biogas plant develops its own adjusted biocenosis and has its own

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composition of volatile fatty acids. Thus, it may be the case that one biogas plant operates at full capacity and performs well, while another plant with the same concentration of volatile fatty acids phases has huge biological problems.

Nevertheless, the absolute fatty acid concentration is one of the main characteristics determining process disturbances. Not only the absolute content of each important fatty acid is important, but also the changes over time.

Unfortunately, it must be considered that determining fatty acids is still not available as online determination (except from a gas chromatograph which is too expensive for this purpose) and needs to be done in an own or external laboratory. Hence, many operators send samples for analyzing the fatty acid content to external laboratories multiple times a year. This is often done in combination with feedstock analysis, nutrient and micronutrient content analysis. A high total volatile fatty acid (VFA) content shows that maybe methanogenic bacteria are inhibited. A further raise of VFA would cause a drop of pH value. While the hydrolytic and acidogenic bacteria would still increase their growth within this condition, methanogenic archaea would at least stop their activity at low pH values. In consequence, a negative cycle would start because the hydrolytic and acidogenic bacteria produce even more organic acids which lowers the pH value even more which in turn inhibits the activities of the archaea. The total volatile fatty acid content therefore should not exceed 4 g l^{-1} expressed in acetic acid equivalent. An optimal pattern for VFA shows higher concentration for lower VFA (acetic acid, propionic acid) compared to lower concentration for longer chain acids. acetic acid equivalent. If longer chain VFA raises compared to acetic acid, the process may be inhibited. (Herrmann C. 2020, Kaiser F. 2010).

Table 1: Proposed upper limits for fatty acid content; © Henkelmann 2010, Kaiser 2011

Proposed upper limits for fatty acids		**[mg l^{-1}]**
Acetic acid equivalent		4 000
From that	Acetic acid	3 000
	Propionic acid	1 000
	Butyric acid	600
Proportion between acetic acid and propionic acid should be 2:1.		

As the substrate used in biogas plants usually has a high buffer capacity, the determination of volatile fatty acids alone may not give enough information to evaluate the digestion process. The higher the buffer capacity, the longer the pH value will not drop, although acid concentration raises, and the process may still run effectively. Several studies searched for possibilities to find an easier and even more precise diagnostic method for determining the process stability. At the end a method was develop called FOS/TAC. It is the quotient of volatile fatty acid concentration expressed in mg l^{-1} acetic acid equivalent divided by the total inorganic carbon expressed in mg_{CaCO3} l^{-1}. Several companies offer special sets determining the FOS/TAC value. Values around 0.4 are fine, while values above 0.8 show process disturbances. If the latter occurs feeding shall be lowered or even stopped until the reason for the process distortion is found and fixed. It must be considered that the effectiveness of this method is still under discussion and again these values cannot be seen absolute as each plant has its own biocenosis.

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1.2 Measurement of foam

Another very disturbing effect for the performance is when foam appears at the substrate surface within the digester. This effect can have many reasons ranging from the change to high energetic and fast degradable feedstock, lack of micronutrients, temperature fluctuations to several process inhibitions through surface active agents (tensides). If the foam building process cannot be stopped immediately, it often ends almost in a standstill of the biogas process. As foam may get into gas pipes etc., it also causes secondary damages. If substrates are used which may cause foam (protein rich feedstock) a surface detection should be installed (ultrasonic), the micronutrient content should be determined more frequently, the feeding should be done hourly and other technical disturbances such as temperature fluctuations should be avoided. If foam occurs nevertheless, one of the fastest countermeasures is to stop feeding, to start stirring, to lower the filling level within the digester and to pump in already further digested substrate from the post digester or from the storage tank. For the latter, it is important not to change the temperature within the digester with this action as this would cause further process inhibition. Also, anti-foaming agents can be used. However, it is important that these anti foaming agents do not create siloxane (Kliche, 2017).

1.3 Measurement of the gas, quality and quantity

The quality of the gas says much about the stability and sanity of the biological process and of course about the energy produced. Thus, all biogas plants are equipped with a device that analyzes gas. It shows the composition of the biogas and gives information about the following:

- CH_4: Is the most valuable component. The higher the CH_4 content, the more energy is in the gas;
- CO_2: the relationship of CH_4 and CO_2 is important in order to determine the stability of the biological process. The CH_4 concentration should be higher than the CO_2 concentration. Changes in the relationship indicate unstable process conditions;
- O_2: indicates if leakages in the gas system occur. If above 1%, the operator should do a leakage control;
- H_2S: toxic and corrosive gas. Can occur in a range of below 100 ppm up to several thousand ppm (mainly depending on the quality of the feedstock). Should be as low as possible. Usually the technical equipment defines to which level H_2S should be reduced. Typical limits for CHP operation are in a range of 50 - 200 ppm;
- H_2: measurement for process optimization.

Excurse, measurement of hydrogen

Information about process stability can be derived from the measurement of hydrogen. Hydrogen, acetic acid and carbon dioxide are the molecules from which biogas is made. An increasing hydrogen content promptly shows a process distortion (BMWFW, 2017). Here, the methanogenetic process is hindered while the first steps of biomass degradation are usually not disturbed. The latter would cause an ongoing acid production while these acids are not transformed to methane anymore and so the pH value will drop. Therefore, the check of the hydrogen content in the biogas is one of the fastest possibilities to monitor if there are possible process disturbances. As with other biological processes, not the total amount of hydrogen is the indicator, but the changes within short periods.

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Flow meter

The flow meter measures the volume rate of the biogas production, typically in m^3/h. This value shows whether the biological process is stable. If this value drops, the living conditions for the microorganisms are not optimal anymore and measures to stabilize the process are important.

Additionally, the biogas production rate indicates if the whole biogas plant operates in an efficient manner and whether the gas yield is according to what is expected from the feedstock used.

1.4 Documentation of data

Over the past years it became more and more important to have a proper data recording, also due to legal requirements. Many legal institutions that are responsible for the permitting procedure and for recurrent inspections of biogas plants request several data to be recorded and additionally demand recurrent self-checks and external audits done by professionals.

Keeping record of self-checks done on safety devices, performed maintenance and external audits done by professionals became more and more important.

While data that are usually measured by the MCR technique are also recorded by that same technique, all other recording needs to be done in a separate logbook. Some MCR techniques also provide a tool to include these data or at least provide a scheduler to set a reminder.

To give a visual impression of how those MCR techniques look like and to allow for a better understanding, some photographs are presented below.

Picture 1: Feeder for bulky substrates with included weighing unit and big display also directly on the device so staff has control when loading the feeder.

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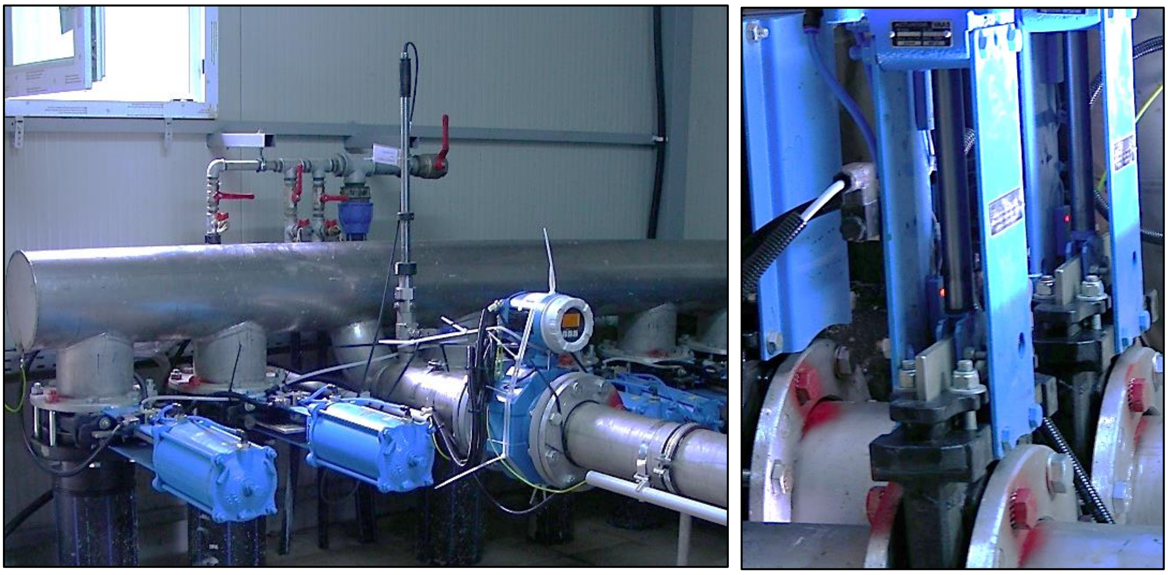
Picture 2: Measurement devices for temperature and level sensors (right: ultrasonic measures from top).

Picture 3: Pumping station with pressure sensor before and after the pump to detect distortions.



Picture 4: Flow meter and contacts within valves giving the actual status of the valves.

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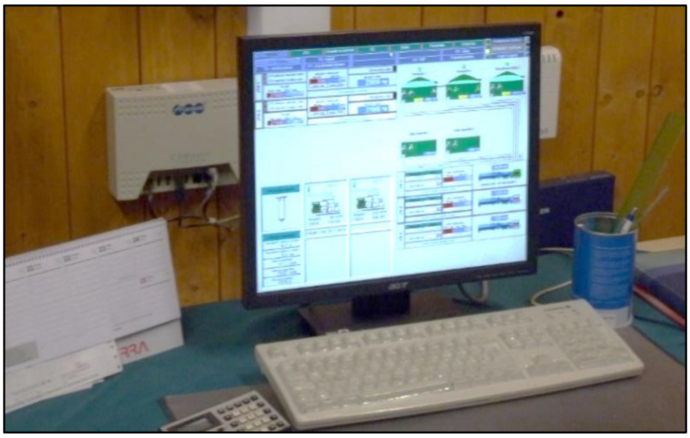
Picture 5: Biogas analysis to detect CH4, CO2, H2S and H.



Picture 6: Visualization of the MCR

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Picture 7: left: inspection hole with camera system, right: manual inspection.

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Digital global Biogas Cooperation

Project website: www.dibicoo.org

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