Overview and Categorization of European Biogas Technologies

- Digestate Storage and Use -

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
HRT	Hydraulic retention time [d]

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1 Digestate Storage and Use

The most recognized product of anaerobic digestion is biogas. However, the second product, digestate (digestate is the effluent of a biogas plant), is also very valuable. AD can be seen as one of the most important techniques that combines renewable energy production with nutrient recycling. Biogas consists mainly of methane, carbon dioxide and very few amounts of hydrogen sulfide and nitrogen. Thus, with the gas mainly carbon, hydrogen and oxygen and only traces of other substances are leaving the biogas system. Nearly all nutrients from the feedstock are remaining in the digestate. Therefore, digestate includes almost all nutrients that came into the process with the feedstock and it can be considered as full compound organic fertilizer. Depending on the feedstock used, also considerable amounts of carbon cannot be degraded and formed into biogas and therefore remain in the digestate as well. Examples include lignin and celluloses which are not or barely degraded in biogas plants and remain in the digestate. These amounts of carbon are valuable sources for humus formation on the field.

For example, phosphorous is one of the essential macronutrients for plant growth and seen as finite resource. Therefore, phosphorus is already seen as critical raw material (COM/2017/490 final), but still gets lost via landfilling and incineration of all kinds of organic waste streams and sewage sludge. This loss of phosphorous will become more and more important in the future. To support nutrient recycling from organic streams, the European Union started a process streamlining the legal situation of nutrients from organics at the beginning of the last decade.

With an amendment, digestate is now included in the EU fertilizer regulation (2019/1009/EG) and could become an EU fertilizing product that could then be sold across borders within the EU without any further restriction. It is important to notice that the moment digestate becomes a fertilizing product under EU fertilizer regulation, it automatically ceases to be considered as waste (Article 19). Furthermore, after setting specific rules for animal byproducts within Article 46, digestate from animal byproducts ceases to be considered as animal byproduct. Additionally, an amendment of Annex V of the REACH regulation (Registration, Evaluation, Authorization and Restriction of Chemicals, 1907/2006/EG) was made. Trough Article 12 of Annex 5 it was clarified that digestate does not have to be registered under REACH anymore.

An advantage of the use of digestate is that the farmer can reduce the money spent for synthetic mineral fertilizer and/or can expect higher crop yields if digestate is used. The following example might illustrate this advantage: The development of biogas plants was mainly driven by European organic farmers in the 1970 and 1980ties (before renewable energy production was supported by the governments). They were not allowed to use synthetic mineral fertilizer on their farms. By operating a biogas plant, they produced their own fertilizer and higher crop yields were achieved. Hence, producing fertilizer may be a huge motivation for many farmers. This aspect is very important especially in low fertilizing systems which are very common in some developing counties, e.g. practiced by many farmers in Africa.

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1.1 Properties and ingredients of digestate

Depending on the feedstock used and the technique applied, the quality of digestate can vary significantly. The following table shows the main characteristics of raw digestate from some example analyses.

Table 1: Main properties and ingredients of raw digestate from energy crops, manure and biowaste (© Kirchmeyr 2016).

	unit	n	10% quantile	arithmetic average	90% quantile
DM content	[%]	2137	2.8	5.8	9.1
organic matter in DM	[% of DM]	1926	55.2	68.9	82.2
pH value		1922	7.5	7.9	8.3
N total	[% of DM]	1857	4.9	10.4	17.8
NH_4-N	[% of DM]	2058	1.7	6.4	13.1
K_2O	[% of DM]	1513	2.0	5.1	8.3
P_2O_5	[% of DM]	1520	1.7	3.7	5.5
CaO	[% of DM]	1180	2.1	4.7	8.0
Mg	[% of DM]	1179	0.3	0.7	1.3
Cr	[mg/kg DM]	1128	6.5	15.8	26.8
Cd	[mg/kg DM]	1102	0.2	0.4	0.6
Pb	[mg/kg DM]	1118	2.2	6.9	11.2
Zn	[mg/kg DM]	1133	160.0	332.0	530.0
Cu	[mg/kg DM]	1134	35.0	94.7	177.7
Hg	[mg/kg DM]	1098	0.0	0.1	0.2

For plant nutrition it is also very important whether the nutrients are bound in the solid material of digestate or available relatively quickly because they are already in the liquid phase. The next figure gives the relevant information and shows that some elements are mainly solved in the liquid (like K) while others (like P) are mainly in the solid phase of the digestate.

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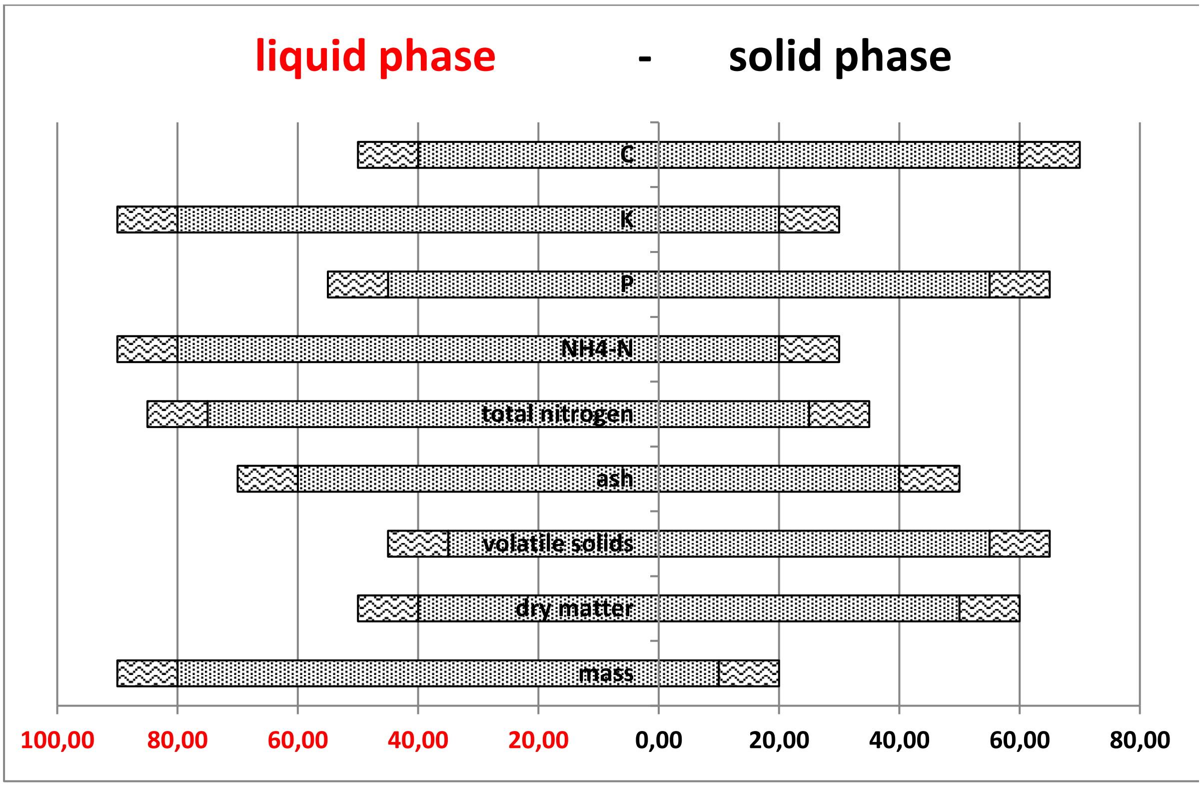

Figure 1: Distribution of nutrients and other relevant parameters between liquid and solid phase of raw digestate [%]; © Fuchs 2010.

Digestate can be further treated, i.e. technically upgraded. With upgraded digestate, concentrated fertilizer can be produced (which can be better transported). Furthermore, a separation of the liquid phase (to be spread on the fields) and the solid phase (to be composted) can be done. So far, the most common techniques used for upgrading digestate are by screw press or decanter. Currently, those are the most developed, the most reliable and the cheapest techniques available. Due to the growing size of average biogas plants, due to an increasing amount of plants and due to the huge efforts made for a circular economy, further upgrading techniques are currently being developed.

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Table 2: Main properties and ingredients of liquid fraction of treated digestate from energy crops, manure and biowaste; © Kirchmeyr, 2016.

	unit	n	10% quantile	arithmetic average	90% quantile
DM content	[%]	205	1.5	5.4	9.2
organic matter in % DM	[%]	173	53.7	65.9	77.6
pH value		157	7.6	7.9	8.3
N total	[% of DM]	186	5.9	13.1	22.0
NH4-N	[% of DM]	183	2.8	8.0	15.7
K2O	[% of DM]	177	4.5	15.9	12.9
P2O5	[% of DM]	177	1.0	3.2	4.5
CaO	[% of DM]	141	2.3	5.1	8.0
Mg	[% of DM]	146	0.4	1.2	1.6
Cr	[mg/kg DM]	119	2.9	12.3	29.6
Cd	[mg/kg DM]	117	0.2	0.4	0.7
Pb	[mg/kg DM]	118	1.0	7.8	18.6
Zn	[mg/kg DM]	121	137.0	361.0	556.0
Cu	[mg/kg DM]	121	27.8	90.8	202.0
Hg	[mg/kg DM]	117	0.0	0.1	0.2

Further information about digestate, digestate use and upgrading can be found in the publication from Fachverband Biogas: *”Digestate as Fertilizer”*.

1.2 Hygienic benefits of digestate

At the beginning of the biogas market development in Europe, the discussion came up of whether digestate might cause cross contamination of different kinds of diseases. As many biogas plants are operated by different types of cooperation between farmers it became evident that there is a strong need for scientific clarification of whether digestate can cause any spread of diseases. Through the used energy crops, straw, crop residues, vegetable waste etc., also weed seeds, unwanted plant propagules from weeds and plant pathogens could come into the digestion process. In order to clarify whether weed seeds, plant propagules or plant pathogens can pass the digestion process without losing its germination respectively sprouting ability, several studies were done (e.g. by Leonhardt et al. 2010). The results showed that a proper digestion process destroys unwanted weed seeds, plant propagules and plant pathogens. For example, their survey shows that even bitter dock (*Rumex obtusifolius*) – one of the most feared weed seeds in agriculture – has only 14 % germinability left after a three-days digestion process at 35 °C and is destroyed after a retention time of seven days. To sum

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it up, the study demonstrates that with a proper digestion process (with a retention time over 7 days and at least 35 °C digestion temperature), the germinability of weed seeds is no problem anymore.

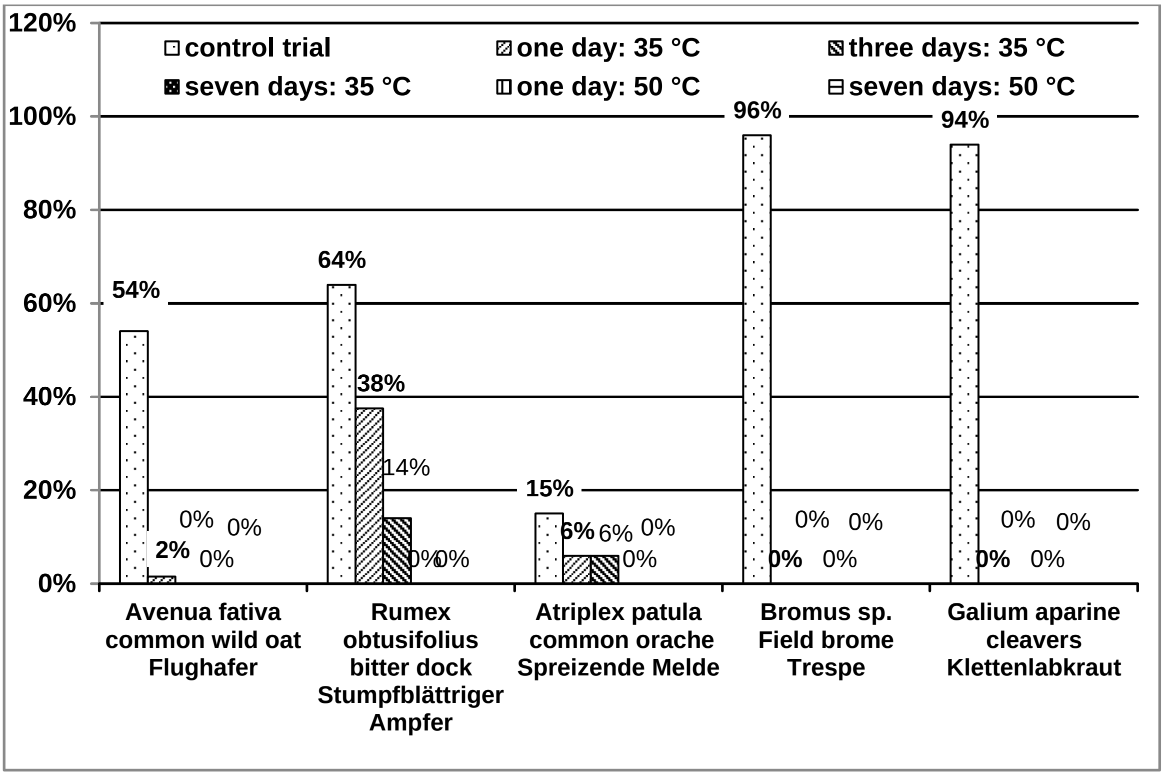

Figure 2: Germination ability of different kinds of weed seeds by 35 °C and 50 °C digesting temperature and depending on the retention time; © Pfundtner 2010.

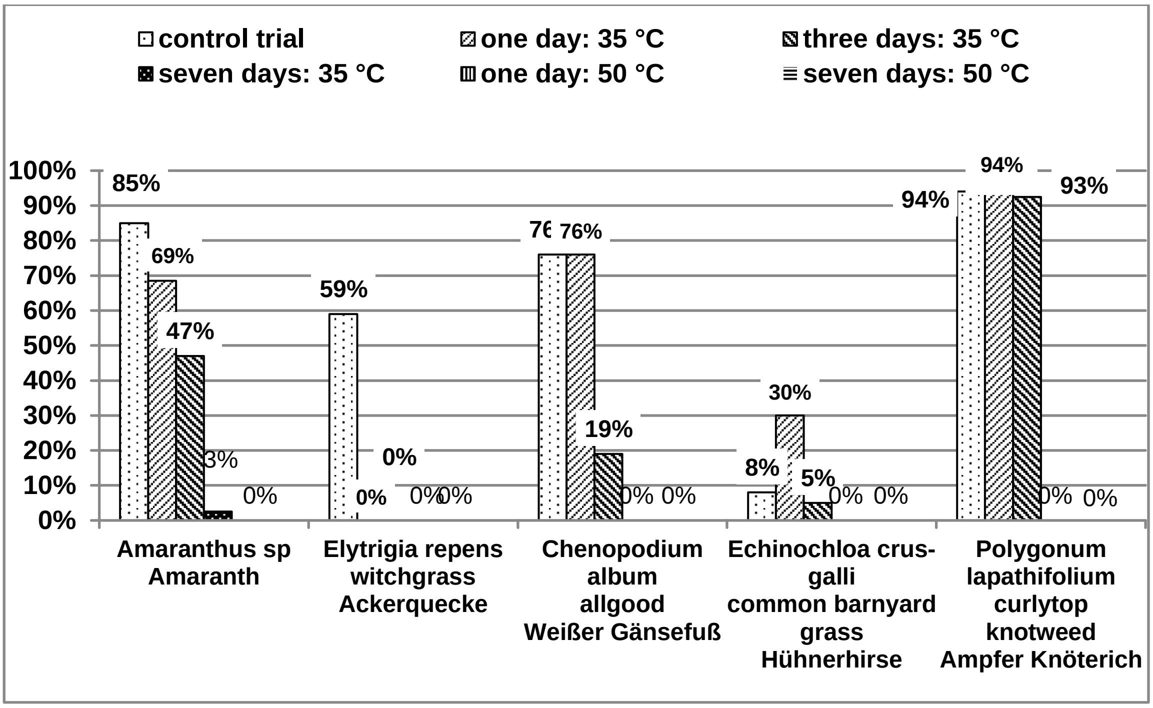

Figure 3: Germination ability of different kinds of weed seeds by 35 °C and 50 °C digesting temperature and depending on the retention times; © Pfundtner 2010.

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As an example: in recent years, Europe faced the invasion of new plants that completely overran existing railroad embankment and other extensively used land. Two of these new invasive plants, the Japanese knotweed (*Reynoutria japonica*) and the weedy yellow nutsedge (*Cyperus esculentus*, Erdmandelgras), were examined with regards to their behavior after digestion. Plant propagules from the Japanese knotweed lost their viability within 7 days at 37 °C. Seeds from the yellow nutsedge lost their germinability within 21 days at 37 °C and within 7 days at 55 °C (Fuchs, 2017).

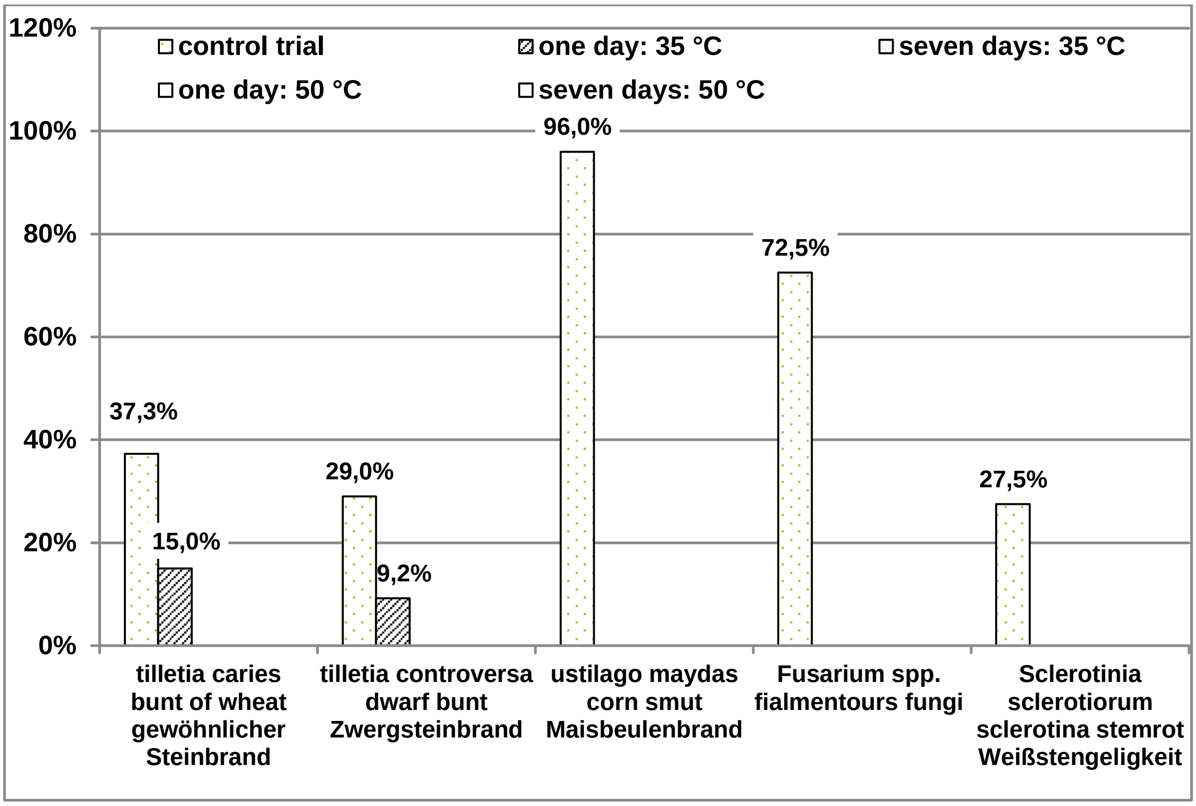

Figure 4: Viability of different types of pathogens in digesters operated by 35 °C and 50 °C after a one-day and seven-day retention time; © Pfundtner, 2010.

In the same report, the Austrian Agency for Health and Food Safety investigated the viability of plant diseases such as corn smut, fusarium, common bunt of wheat *Sclerotinia* and dwarf bunt. All of them lost their viability within one week when the digestion temperature was at least 35 °C.

Additionally, a much-discussed topic is the viability of pathogens because biogas plants are designed to offer the best growing conditions for bacteria and archaea. IEA task 37 elaborated a brochure specifically on this topic by summarizing several studies. The results (summarized by Lukehurst, Frost, & Al Seadi, 2010) show that eggs of common gastrointestinal worms and larvae of lungworm were inactivated after an eight-days retention time with a digestion temperature of at least 35 °C. Increasing the temperature to 53 °C would induce an inactivation already after less than 4 days. Many common viruses, e.g.: bovine viral diarrhoea (5 minutes at 55°C; 3 hours at 35°C) and Aujeszky's disease in pigs (10 minutes at 55°C; 5 hours at 35°C) and Johne's disease in cattle (M .Para tuberculosis after 0.7 hours at 55°C, 6 days at 35°C) died already under mesophilic conditions in the anaerobic digester.

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Further studies show that in case there are pathogen bacteria in the feedstock, they will be reduced during the process. This was investigated for several stems of bacteria. The reason is probably that the bacteria inside a digester are adapted best to the feedstock that is fed into the digester. Those bacteria that degrade sugars, fat and proteins are dominant in the process and pathogen bacteria do not endure the concurrency with the well adapted (not pathogenic) bacteria.

However, if very high amounts of pathogen bacteria are fed into the process, they will only be reduced, but not eliminated completely. Most types of biowaste and animal by-products (e.g. slaughterhouse wastes, household wastes, meals from canteens etc.) need to be sanitized in order to eradicate or reduce animal pathogens to an acceptable and low sanitary level. This does not apply for manure which can be spread directly on the fields for as long as digestate from manure is not listed under EU fertilizer regulation.

There are several techniques of sanitization including the following:

- Pasteurization which is done in a batch reactor. The material is heated up to above 70 °C for at least 1 hour. The particle size should not exceed 12 mm. Pasteurization can be done upstream for only the fraction of waste that might contain pathogens. The heated material also helps to transfer the heat to the subsequent digestion process. Another method is to pasteurize all digestate. However, the fact that all digestate must be treated (not only the contaminated part) makes this procedure disadvantageous as it is more expensive and needs more energy.
- Thermophilic digestion; if the feedstock is digested in a thermophilic (> 50 °C) process and the hydraulic retention time (HRT) is above 14 days, then the digestate can be considered to be sanitized.
- Thermophilic composting if the material is sanitized in the same way as during thermophilic digestion, i.e., at >50 °C and for longer than 14 days.
- Other validated methods - if the operator of a biogas plant can prove that other methods (like shifting the pH-value) ensure sanitization, these methods can be accepted as well.

1.3 Benefits of digestate as organic fertilizer

For the plant operator and for appliers of digestate, the effect on soil microbes and aggregate stability is of high importance. In order to understand the different impact on soil microbes etc. by digestate and by untreated raw farm fertilizer, a closer look into the digestion process is needed. Besides degrading carbon and building up biogas from it, microbes also degrade unwanted volatile organic compounds (e.g. iso-butonic acid, butonic acid, iso-valeric acid and valeric acid, along with at least 80 other compounds).

If untreated, the latter would cause an unpleasant odour when released to the atmosphere and would also have a negative impact on the soil microorganism. The following figures show the degradation of organic compounds within the digestion process, a comparison of GHG emissions by untreated and by digested farm fertilizer and the reduction of several types of volatile fatty acids during the digestion process.

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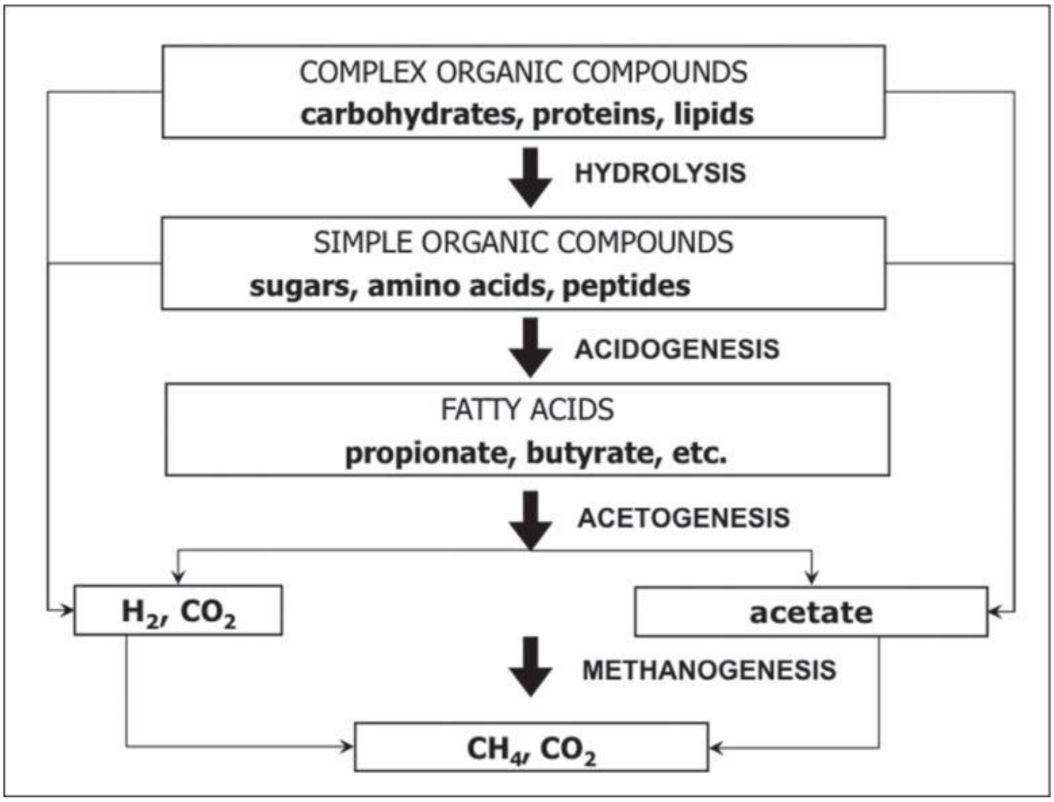

Figure 5: Degradation steps of organics within the anaerobic digestion process; © Drosg 2013.

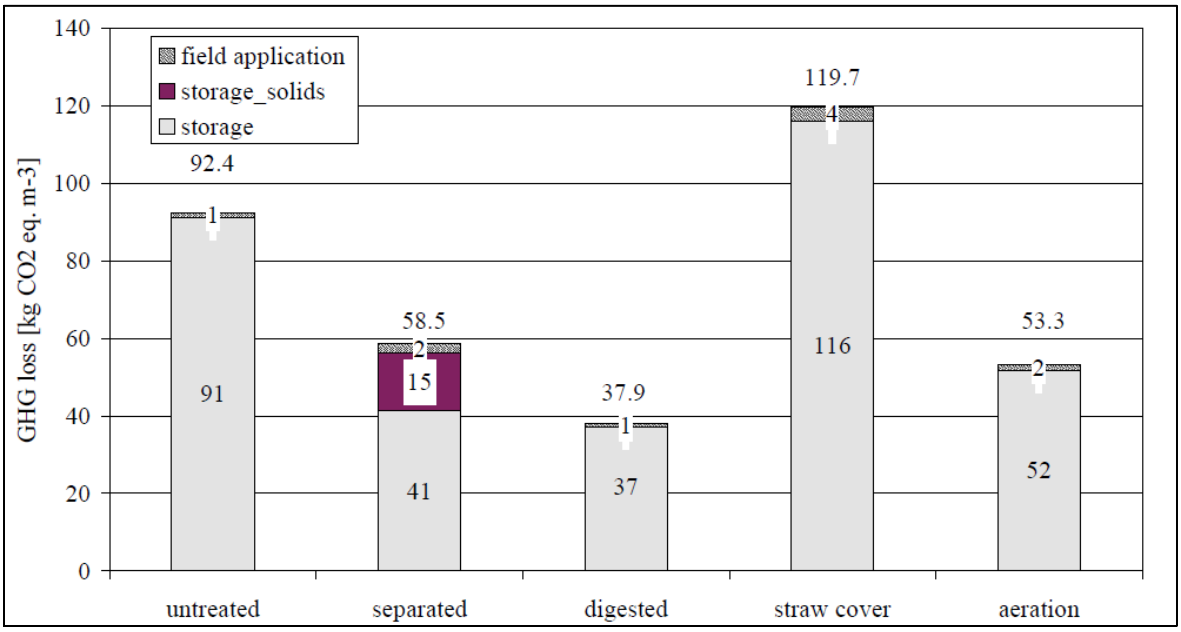

Figure 6: Greenhouse gas emissions during storage and after field application of dairy cattle; © Amon 2002.

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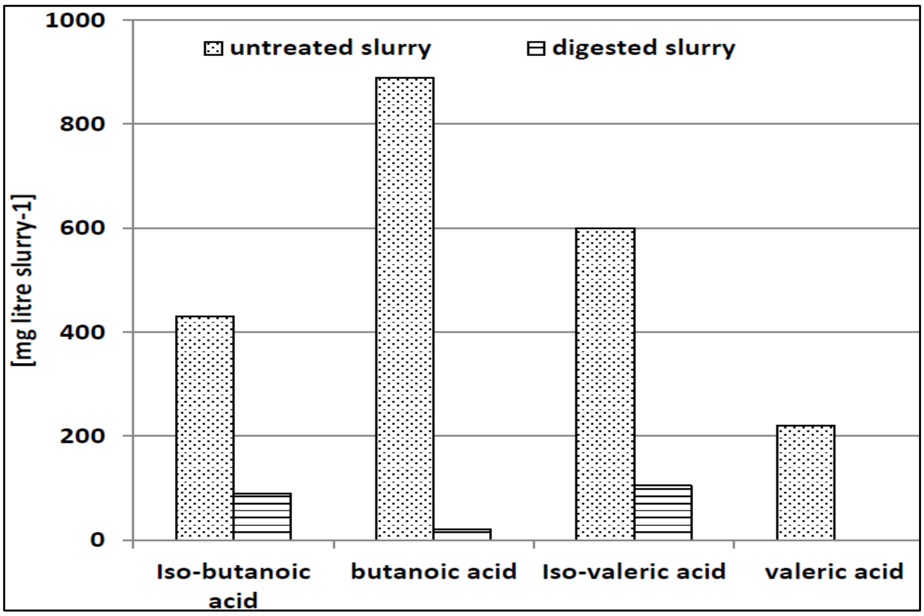

Figure 7: Concentration of different kinds of volatile fatty acids in raw farm fertilizer and digested farm fertilizer; © Hansen 2005.

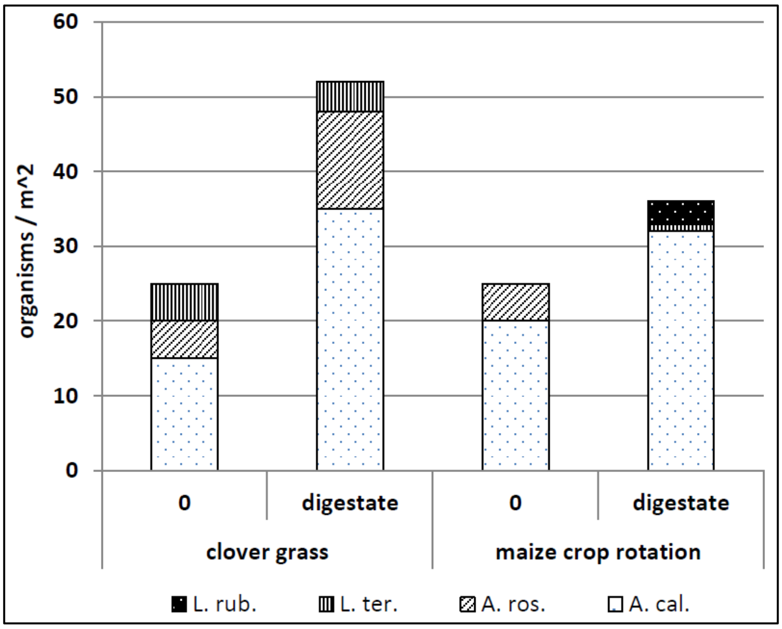

Figure 8: Presence of different kinds of worms in soil without application of digestate (=0) and with application of digestate to different crop rotations; © Hülsbergen 2016.

Due to this positive effect of digestate on soil microorganism, we can also expect a positive impact on the aggregation stability of soil. This was investigated by Hülsbergen 2016 and is shown in the next figure.

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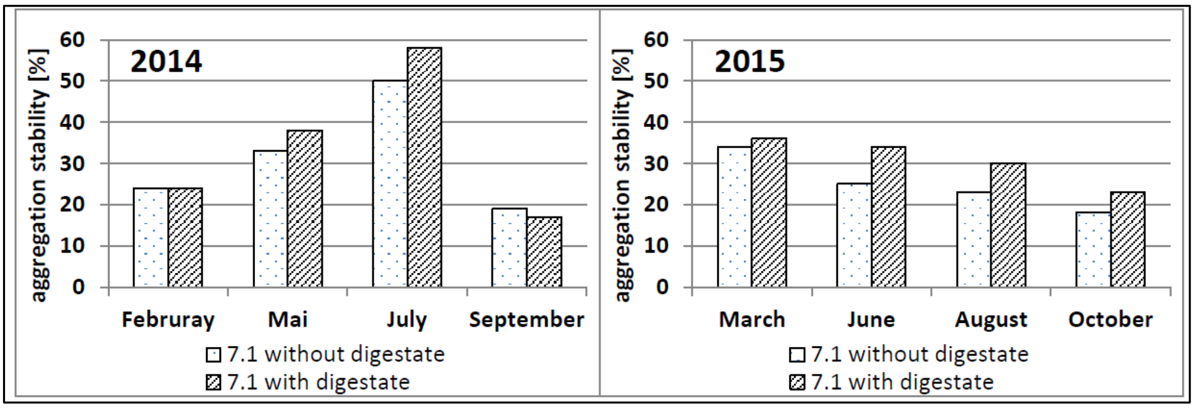

Figure 9: Comparison of aggregation stability of soil without application of digestate and soil aggregation stability with application of digestate; © Hülsbergen 2016.

In his research Petz (2000) comes to the same conclusion. He discovered a significant increase of the microorganism population, a higher aggregation stability and a significantly higher field capacity of around 13% thanks to the perennial application of digestate. The latter can be very important when looking at the climate change and the associated change of whether (intensity of rain and annual rainfall). Another reason why digestate has a positive effect on soil is its humus forming capacity. With his research, Reinhold already showed in 2008 that digestate has a very important capacity in forming humus (as shown in Figure 10). Nielsen et al. also compared carbon stability after application to silty sand in 2018. Within 500 days carbon from bovine manure had the lowest mineralization rate (15%) while carbon from different kinds of digestate mineralized between 25-47% (but was still below bovine slurry with a mineralization rate of around 50% and wheat straw with a mineralization rate of nearly 70%). Digestate significantly improved the aggregate stability of the soil, comparable to bovine slurry and a bit above bovine manure.

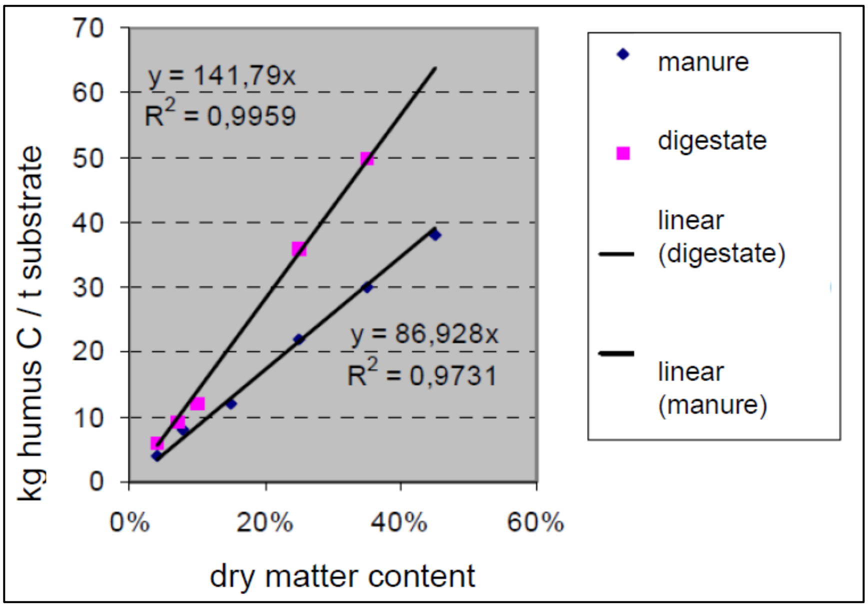

Figure 10: Comparison of humus forming possibilities of untreated manure and digestate; ©Reinhold & Zorn, 2008.

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Finally, two comparisons show the effect of digesting catch crops and straw. Based on research from Szerencsits in 2014 on yields of different kinds of catch crops and their organic matter losses during winter season Kirchmeyr (2016) did a comparison within BIOSURF between rotting the growth during winter time and on the other side harvesting the growth from catch crops and use the digestate as organic fertilizer.

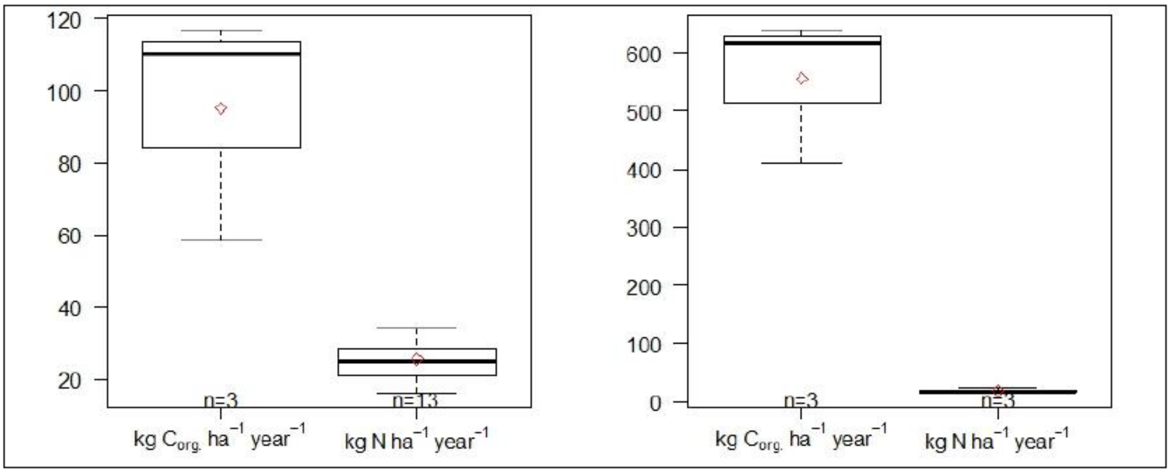

Figure 11: Rotting process of catch crops during winter periods: left: losses of $C_{org.}$ and N per ha into ground water; right: losses of $C_{org.}$ And N per ha into atmosphere; © Szerencsits 2014.

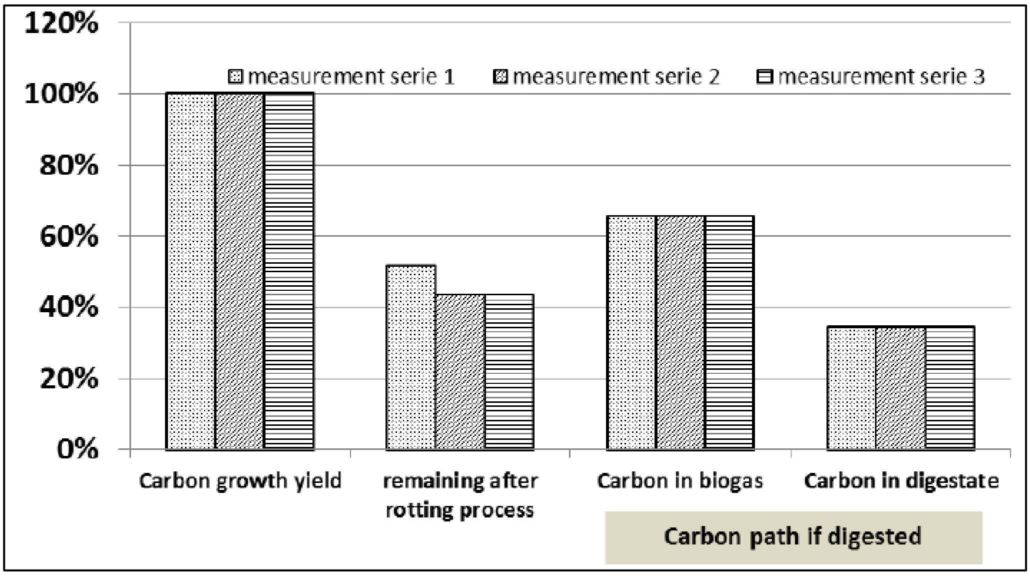

Figure 12: Comparison of Carbon path from catch crops: a) catch crops stay on the field to rot, b) growth of catch crops are harvested, digested and digestate is brought back to field; © Kirchmeyr 2016.

Important to notice is that N will be fixed during the digestion process and therefore losses can be minimized. All in all, reaching high yield second crops may help significantly in avoiding wind and water erosion, raising soil fertility and combined with anaerobic digestion additional energy can be produced and nutrient losses minimized.

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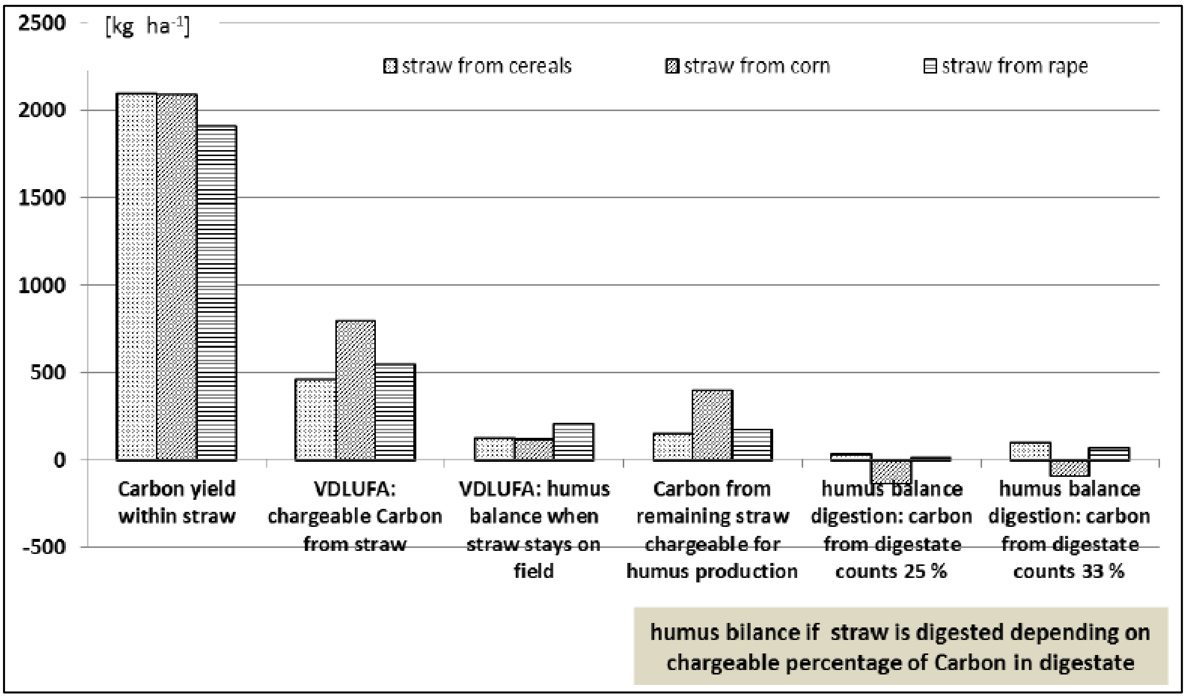

Figure 13: Humus forming ability of rotting process of straw compared to harvesting and digesting straw; © Kirchmeyr, 2016.

Depending on the calculation method for humus balance and here especially of the factor for the humus forming capacity for different kinds of carbon, harvesting and digesting certain amounts of grown straw may not have a negative impact on the humus balance compared to rotting the straw.

1.4 Impurities

When digestate is used as fertilizer for plant nutrition, the aspect of possible impurities needs to be considered. When the used feedstock comes only from pure fractions like energy crops, straw, farm fertilizer and by-products from food, feed, beverage and renewable transport fuel, this aspect is less important. However, when organic waste streams from households, catering, sewage sludge etc. will be digested, a closer look on possible impurities is needed. Problematic impurities might be plastic, metal (especially heavy metals), glass, antibiotics, pharmaceutic residues and other chemicals that should not, or at least only to a minor degree, be spread on fields. Within the EU, the special requirements in Annex II of the recently amended EU fertilizer regulation (2019/1009/EG) have to be fulfilled.

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Table 3: EU fertilizer regulation Annex II: upper limit values for impurities

EU fertilizer regulation Annex II: Restrictions on impurities (glass, metal, plastics)			
Size [mm]		amount [g kg_{DM}^{-1}]	
∑ of macroscopic impurities: (glass, metal or plastics)	> 2	5	In total
	> 2	3	For each separately
		2.5	For plastics: From 16.07.2026 on
		Reassessment before 16.07.2029	

Each digestion plant, treating organic waste that might include impurities, uses an impurity removal device before the digestion process. However, it might be necessary to perform a second check in order to ensure that the above listed requirements from the EU fertilizer regulations are fulfilled. Another reason for this second step is that no plant operator wants to spread undesired impurities on agricultural fields. Such an additional step is usually done by sieving the whole digestate directly before it flows into the storage tank. Several investigations of digestate demonstrated the efficiency of this device.

When animal by-products are fed into the digester also a sanitation step is required. This is usually done *before* the substrate is fed into the digester. The reason behind this is efficiency and a kind of pre-treatment of feedstock during the sanitation process that allows for a faster degradation of organic material within the digestion process.

In special cases it could also be done *after* the digestion process but the digestate should then be stored in a gastight storage tank which is connected to the gas system so that remaining biogas will be collected.

1.4.1 Separation, drying and further upgrade

In smaller biogas plants digestate is usually stored untreated. It can also be upgraded for several reasons:

- Producing recyclate which is needed to avoid too high DM content in the digester
- Producing a solid phase which can be sold to consumers
- Producing marketable fertilizing products

The most common technique to dewater digestate is by using a screw press.

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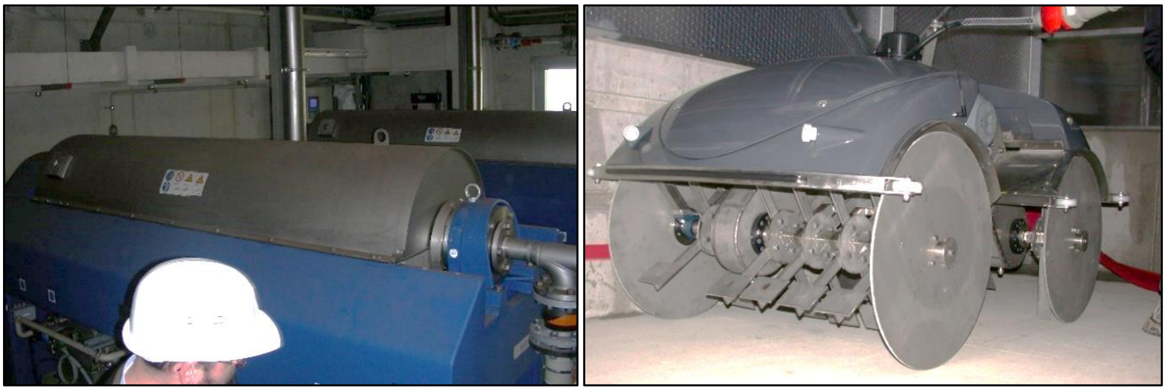
Picture 1: Screw press to dewater digestate

Also applied in warmer regions are sun-drying systems where the digestate is filled into a glass house and is turned via automatically driven turner. Important is that during the drying process also ammonia and other gases, like N_2O might be released. These emissions should be limited because some gases are potential Green House Gases, like N_2O. Ammonia losses should be limited because a loss of ammonia is also a loss of nitrogen which is an important fertilizer.



Picture 2: Left: decanter, right: automatically driven digestate turner

Figure 14: Post-composting of digestate from a dry fermentation process; left: in a closed hall with automatic aeration through the compost windrow and collection and cleaning of exhaust air in a biofilter, right: windrow post-composting in an open hall

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Also used in practice are dryer belts through which the digestate is dried with warm exhaust air from the CHP. The dried digestate can be pelletized and sold for small gardening etc. As ammonia will go into the gas phase to some extent, it is important to remove the ammonia from exhaust air before its release into the atmosphere.

If the digestate process is done in a dry digestion process, then what follows the digestion is usually a composting process. During the last years several research programs were conducted to further upgrade digestate into a product which can directly replace mineral fertilizer. These techniques are stripping, membrane filtering, osmosis etc.

1.5 Digestate storage and application technique

As digestate is a valuable organic fertilizer, it should be applied in periods of plant growth. Depending on the climate conditions where the biogas plant is constructed, this might require that digestate is stored over longer periods when application would not bring benefits for plant growth or would even pollute the environment (e.g. during winter season).

In Central Europe with its long winter periods, the usually required storage time is 6 to even 9 months. Most storage tanks are made by in situ concrete, precast concrete or lagoons with double membranes and tightness monitoring. Storage facilities can be built in open or airtight versions. The latter is required more and more due to possible methane and laughing gas emissions from storage tanks.

Covered storage tanks require an installed stirring system that is fixated while open storage systems often use these systems as well but can also use mobile stirring devices. Compared to the application of raw farm fertilizer, the use of digestate offers several positive effects as mentioned above. Because the percentage of ammonia within the total nitrogen content is higher compared to the one of farm fertilizer, the application should be done with devices that lower the release of ammonia into the atmosphere. Usually this is done with slurry tanks with additional trailing hoses or slurry cultivators. When digestate is applied to cereals or grassland during vegetation season, slit injection is also an option. Additionally, the loading from storage tank into transport tanks and from transport tanks into the field-application-device should be done in closed connection.

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Figure 15: Glasshouse with vegetables grown on effluat from digestate screw press

Picture 3: Digestate storage tank: top left: open storage tank, top right: airtight gas storage tank with a double membrane layer and connection to the gas system, below: open lagoon with double layer membrane to monitor tightness

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Picture 4: For the transport over longer distances trailers are used often

Picture 5: Top: filling station for slurry tanks and slurry tank with trailing hoses; Bottom: slurry spreader without tank and slurry tank with slurry injection

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The DiBiCoo Consortium

COORDINATOR

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

PARTNERS FROM EXPORTING COUNTRIES

WIP RENEWABLE ENERGIES

AUSTRIAN ENERGY AGENCY

EBA European Biogas Association

kompost & biogas verband

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Digital global Biogas Cooperation

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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