

Digestate as Fertilizer

BIOGAS Know-how_4

giz

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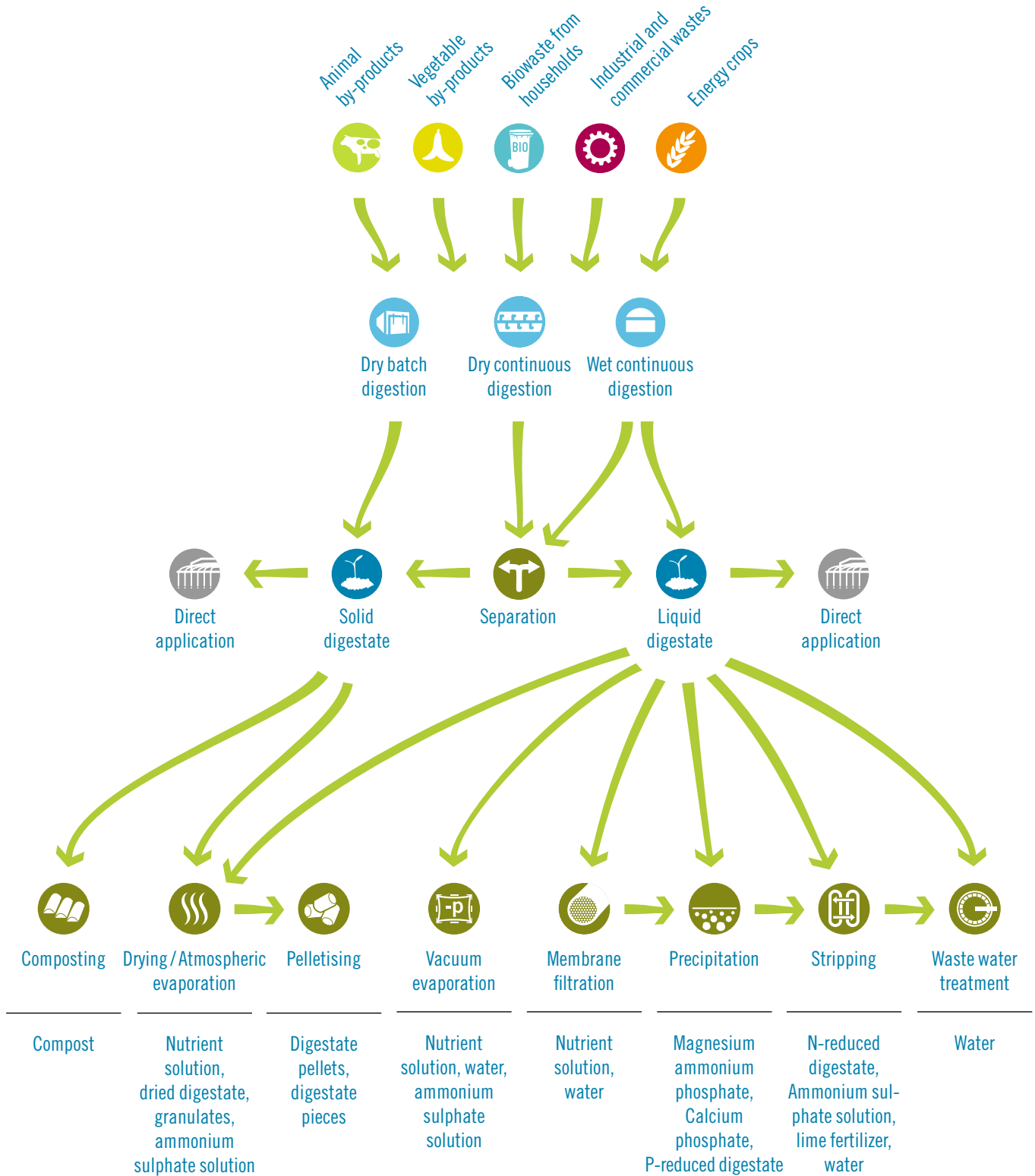


**Fachverband
BIOGAS**

German Biogas Association
www.biogas.org

DIGESTATE AS FERTILIZER

Application, upgrading and marketing



The depicted symbols are consistently used throughout the brochure and as a classification system of the different companies in the directory.

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Statements



‘Digestate is the ideal precursor for sustainable and fruitful agriculture. By using it as fertilizer, nutrient cycles are closed, and at the same time, mineral fertilizers with a considerable carbon dioxide (CO₂) footprint are conserved. The microbiological digestion process has a hygienic and stabilising effect on the feedstocks used. This provides high-quality digestate, rich in nutrients and humus.’

– **Horst Seide, President of the German Biogas Association**



‘Energy is a fundamental part of sustainable development. From a development policy perspective, biogas offers many advantages; from the creation of jobs and provision of decentralised clean energy for rural development, reduction of greenhouse gases, improvement of organic waste management practices as well as upgrading and utilisation of organic fertilizer from the biogas production process, substantial co-benefits can be provided, such as better crop health and additional income for small-holder farmers.’

– **Dr Christoph Beier, Vice-Chair of the GIZ Management Board**



‘Biogas digestate, often referred to as ‘brown gold’, can definitely be an answer to the poor nutrient supply and poor soil structure in low-input agricultural production systems that we see in many countries today. There is still a lot of room for deepening the scientific understanding of this subject in order to enhance sustainable agriculture and promote organic farming. This brochure points out the significance of biogas digestate throughout the world for minimising the mineral fertilizer footprint. Efforts made towards redefining a ‘biogas plant’ as a ‘biogas and digestate plant’ will significantly augment the notion of sustainability that is on offer from the biogas industry.’

– **Gaurav Kumar Kedia, Chairman of the Indian Biogas Association**



‘The new European circular economy package is a fantastic opportunity for Europe’s bio-resource industry. Biowaste will now be collected separately and recycled into quality products, with the potential of creating over 50 thousand jobs across Europe. This will benefit the economy, citizens and the environment.’

– **Henrik Lystad, Chair of the European Compost Network**

Preamble

Agriculture is one of the fundamental economic sectors of any country. The variety of goods provided by agriculture ranges from food and animal feed to products for the industry and in recent years also increasingly for electricity, heat, and fuels based on energy crops.

However, modern agriculture should always focus on the **responsible use of natural resources**. Agriculture is thus facing the challenge of operating as efficiently, sustainably, and in a manner that is as environmentally friendly as possible. Agriculture must become more efficient in the coming years because agricultural land will have to feed more and more people, especially in view of global population development.

Responsible use of fertilizers plays a decisive role here in maintaining the production of agricultural products at a consistently high level. Global consumption of the most important fertilizers on the world market, potassium, nitrogen, and phosphate, has risen steadily over recent years. However, like any other raw material, the natural sources of these fertilizers are finite. Experts predict a supply problem in the future, especially with regard to phosphorus reserves.

Furthermore, responsible handling of fertilizers is also increasingly being discussed in public regarding water pollution. Only **appropriate use of fertilizers** can ensure that they are not washed out into groundwater or contaminate surface waters.

When operating a biogas plant, the focus should not only be on energy production, but also on the nutrients contained in the digestate that make a high-quality

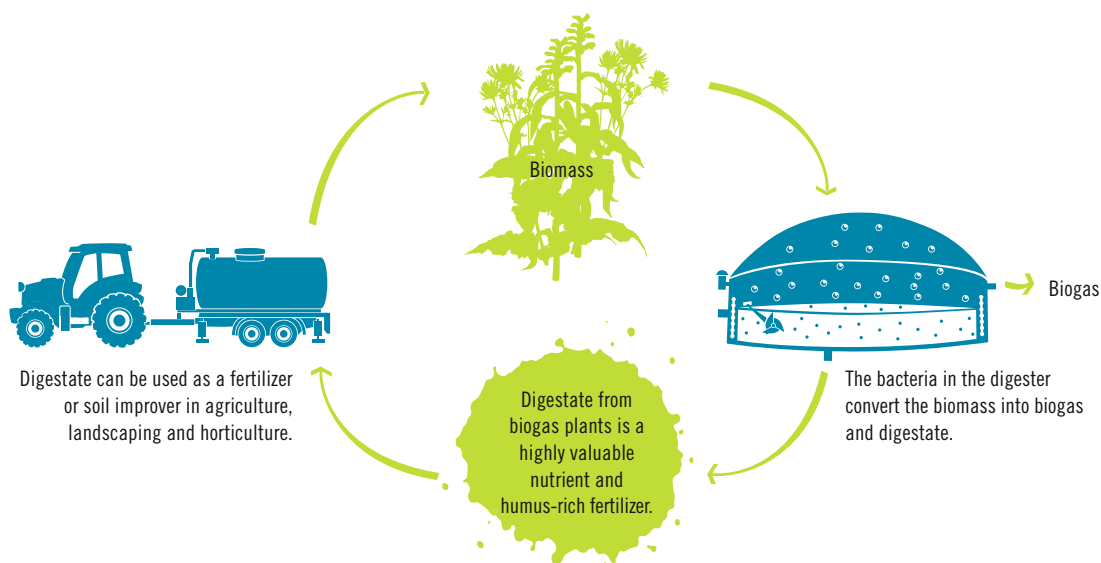
fertilizer. The biogas process allows the individual nutrients to be circulated, which enables ecologically sensible energy production. The nutrients that have been extracted from the soil, either directly via specially cultivated energy crops or indirectly via excrements or biowaste that is disposed of, can be recycled in biogas plants after energy production and can be further used for plant production. A **wide range of applications** is possible, because the digestate produced in the biogas process can either be applied directly or conditioned by various treatment techniques. In addition, this offers the option of reducing storage and transport costs and, if necessary, achieving additional revenues by marketing digestate and at the same time applying nutrients more precisely and more cost-effectively in order to ensure optimal supply to the plants.

This brochure was specially designed for the biogas industry taking into consideration **increased agricultural requirements** and current developments in the field of fertilization. The reader is shown economic options that can be integrated into an individual operating concept. In this brochure, numerous members of the German Biogas Association present their concepts, products, and solutions that are already being applied in practice in order to ensure sustainable biogas production in the long term.



1 Introduction

Some 128 million tonnes of digestate are produced annually in the 13,000 biogas plants in Europe. These fertilizers contain valuable ingredients that are used to supply plants with nutrients and build-up humus and structure in the soil. Thus, in addition to the regenerative CO₂ cycle in biogas production, all other material cycles are also closed.



In biogas plants, biomass is used as a feedstock which is converted into biogas by the activity of various microorganisms and used for energy (see Chapter 2: “Production of biogas and digestate”). What remains is a material from which energy in the form of hydrocarbon compounds has been extracted, but in which all other constituents used are still contained. This **digestate** is largely stabilised after sufficient anaerobic digestion and can be used as **high-quality fertilizer** or as a **soil improver** in agriculture, in soil works, and in horticulture and landscaping (see Chapter 4: “Possible applications”). With the appropriate application rate, the **nutrients** contained in the feedstock, such as nitrogen, phosphorus, potassium, sulphur etc. and other micronutrients will cover the nutrient demand for plant growth. Non-degraded stable carbon compounds additionally lead to **humus and structure formation** in the soil and thus increase its fertility, functionality, microbial activity, aeration, and water storage capacity.

The **agricultural application** of digestate corresponds to the state of manure spread-

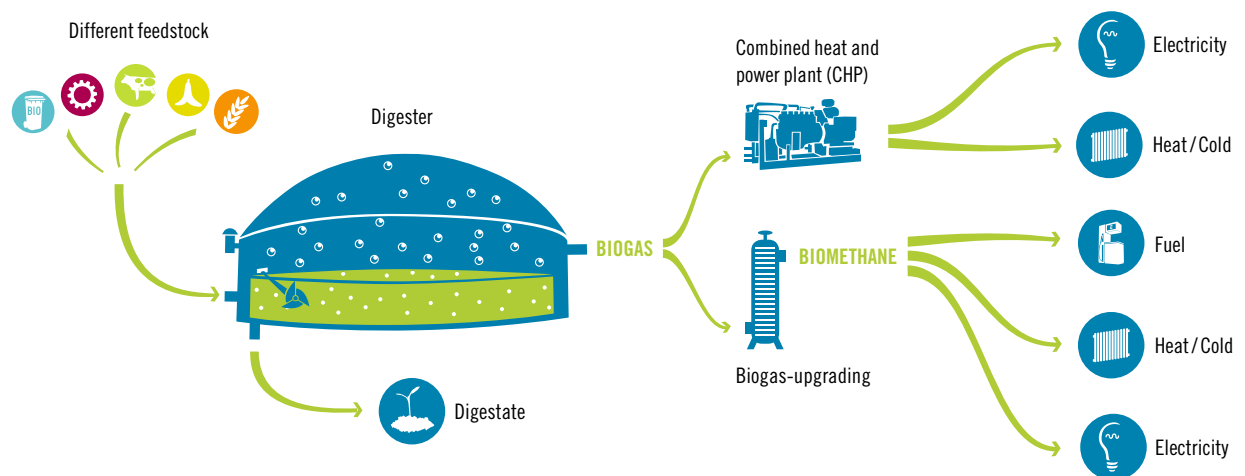
ing (see Chapter 5: “Application techniques”). Whether the digestate is in liquid or solid form must be differentiated. The application rate depends on the ingredients in the digestate and the nutrient requirements of the plant. In Europe, and especially in Germany, far-reaching fertilizer legislation must be observed in order to avoid nutrient losses in air and water in particular (see Chapter 3: “Legal requirements in Germany and Europe”). Requirements for good fertilization practice can vary greatly from region to region, as differences such as crop yields, soil conditions, and precipitation should be considered. The use of digestate plays an important role especially in developing countries because mineral fertilizers are often too expensive and nutrients from organic sources are very welcome (see chapter 9: “Significance of digestate in developing countries”). Furthermore, using digestate saves on mineral fertilizers and thus CO₂ emissions and finite **resources** because producing nitrogenous mineral fertilizers is very energy-intensive. Phosphorus and potassium are mined and contain increasingly higher amounts of cadmium and uranium.

Peat-free products are increasingly in demand from consumers in the production of soils and organic fertilizers. **Substituting peat** for digestate is thus a climate-neutral alternative.

New marketing strategies for conditioned digestate for private gardeners, garden and landscape companies, soil works, and fertilizer manufacturers are becoming increasingly important in order to achieve higher added value for digestate (see Chapter 7: “Marketing strategies”). This requires suitable processing techniques (see Chapter 6: “Digestate upgrading techniques”). The prices for organic fertilizers in agriculture can be very high, especially in areas with high animal populations and the resulting nutrient surpluses and shortage of land. Processing digestate can help to reduce the necessary costs for storage, transport, and application by reducing volumes, concentrating nutrients, and optimising handling. Whether this is an economical alternative must be considered on a case-by-case basis.

2 Production of biogas and digestate

Biogas, a versatile primary energy source, is produced via decomposition of organic materials by various microorganisms in the absence of air. This natural process occurs in nature in a similar way - e.g. in the digestive system of cows. Biogas and digestate are produced in biogas plants under controlled conditions, which make a valuable contribution to reducing greenhouse gases.



Biogas is a mixture of high-energy methane (CH_4) and carbon dioxide (CO_2). It can power a combustion engine similar to that in a car, which, when combined with a power generator, is called a combined heat and power plant (CHP) that supplies both electricity and heat/cold. Alternatively, CH_4 can be separated from CO_2 in an additional upgrading step and fed into the natural gas network as biomethane. From there it is used as fuel for natural gas vehicles or in turn as natural gas for electricity and heat/cold production.

The feedstock for every biogas process is organic material that is metabolised by various microorganisms. In addition to cultivated energy crops, such as maize and grain silage or wild plant mixtures, slurry, manure, biowaste, industrial waste, and vegetable residues are also used. Since only organic materials are decomposed in the process, the composition of the feedstocks plays a crucial role in the **nutrient content of the digestate**, which is produced after the biogas process and used as fertilizer.

During the biogas process, the feedstocks introduced into the digester are decomposed by bacteria. In order for the process to be economically efficient, the microorganisms involved should find optimal living conditions. This includes the appropriate temperature, which in most cases is around 40°C (mesophilic) or $50\text{--}55^\circ\text{C}$ (thermophilic), an adjusted pH value, the absence of oxygen, and a good supply of necessary nutrients. If these environmental conditions correspond to the requirements of the bacteria, the biomass is converted into biogas in four phases. During the first phase, which is called **hydrolysis**, the starting material is broken down into simpler compounds, such as sugars, fatty acids, and amino acids. The microorganisms involved release various enzymes that decompose the material. During the second phase, the intermediates formed are further degraded by acid-forming bacteria as part of acidogenesis. In addition to various fatty acids, CO_2 and water are also produced. The lower fatty acids are used to produce the raw materials for the biogas. They are formed in **acetogenesis**, in which acetic acid-forming bacteria convert the fat-

ty acids to acetic acid, hydrogen (H_2), and CO_2 . Acetic acid, in particular, serves as the basis for the production of biogas, as it is converted from strictly anaerobic methanogenic archaea to CH_4 during the final stage of the process, **methanogenesis**. Another type of archaea produces the CH_4 from the utilisation of H_2 and CO_2 .

In most plants, the four stages of the process take place simultaneously. However, because the different bacteria make different demands on their habitat, a technical and biological compromise must be found in order to ensure optimum utilisation of the feedstocks used. Undesirable components such as weed seeds or pathogens could be introduced into the system and further distributed via the feedstock. Numerous studies have shown that the microbiological processes at thermophilic temperatures in biogas plants lead to proven inactivation of germinable weed seeds and various pathogens. Under mesophilic conditions, they are already significantly reduced. Digestate from biogas plants can, therefore, be classified as hygienically harmless.

The biogas process is identical in all **plant types**, but there are some essential distinguishing features with regard to technical design. Wet digestion concepts are thus mainly used in the agricultural sector. If the feedstocks contain a high dry matter (DM) content or larger quantities of coarse components, dry digestion concepts can be the method of choice. This is the case with many biowaste digestion plants.

Since only part of the organic compounds are decomposed during the process, the mineral part remains almost completely in the digestate. Due to its high content of nutrients, the digestate is an attractive organic fertilizer that is mainly used in agriculture, but also finds new markets in horticulture and among private customers. In addition to the high content of nutrients available to plants, digestate has further advantages over conventional agricultural fertilizers such as manure and slurry. For example,

the odour emissions that occur during use are significantly reduced due to the degradation of volatile organic compounds in the decomposition phase. Furthermore, organic acids are largely broken down and the risk of leaf burns is significantly reduced. In addition, digestate flows better off the leaves because part of the organic material of the original feedstock has been metabolised to CH₄ so that leaf contamination is also reduced. In addition to these advantages, the digestate also contains relevant amounts of humus-effective carbon. In contrast to the use of mineral fertilizers, long-term fertilization with digestate therefore contributes to maintaining **soil fertility** as well as **soil life** and to ensuring high-yield sites that can be sustainably utilised.

Since the nutrient composition of the digestate depends on the feedstocks used, no general information on the nutrient content can be given. Due to the individual feedstock

mix of the plants, which ranges from energy crops, manure and slurry to a wide variety of organic waste, digestate never has identical nutrient contents. Although a range of the most important nutrients and associated mean values can be given on the basis of analysis data, in order to guarantee fertilization according to good professional practice, the digestate must ideally be analysed in the laboratory several times a year. A plant can only be fertilized as required if the nutrient content of the digestate is known.

In addition to energy production, the **circulation of nutrients** is, therefore, also a major advantage of biogas technology, which will receive even more attention in the future. In addition to the positive ecological effects, the sustainable use of digestate also leads to monetary advantages for the plant operator when high-priced mineral fertilizers are replaced or new marketing channels are opened up.

3 Legal requirements in Germany and Europe

Relevant legal regulations are necessary to regulate the requirements and environmentally compatible use of fertilizers. These can be set at a regional, national or continental level. In Europe, for example, the European Fertilizer Regulation applies, which in future will also include digestate from biogas plants and composts.

When the Treaty of Lisbon entered into force in 2009, free trade and free movement of goods within the European Union was established. This means that fertilizers authorised in one Member State may also be marketed in any other EU country. However, as the requirements for fertilizers can vary greatly depending on national law and the existing Fertilizer Regulation of 2003 so far only included mineral fertilizers, amendments were needed. Currently, the EU **Fertilizer Regulation** is under revision by the European commission, parliament and council. The aim of this revision is the harmonisation of rules for **marketing mineral and**

organic fertilizers as well as better **monitoring and control** of fertilizers with the generally valid European CE marking. Essentially, **limit values** are set for **heavy metal** contents and **foreign substances**, and additionally minimum content **requirements for nutrients** must be fulfilled in order for them to receive the CE label as an EU fertilizer and thus continue to be freely marketed in Europe. Digestate from biowaste can also

be classified as a „product“ if the requirements of the EU Fertilizer Regulation are met, e.g. with respect to sanitation.

Overall, the EU Fertilizer Regulation contains 11 **Components Material Criteria (CMC)**, stating what fertilizers may consist of. These are, for example, digestate and compost. Each of these CMCs has specific requirements that have to be met. The requirements for the category of digestate are shown here as an example of suggested values. Currently, discussions about the exact values are still ongoing and may be different in the final regulation.

Impurities (> 2mm)	Plastics (> 2mm)	PAH ₁₆
≤ 5g/kg [sum]; No more than 3g/kg dm of macroscopic impurities in either form of glass, metal or plastics above 2mm	≤ 2,5g plastics/kg DM After 7 years of the date of application of this Regulation	≤ 6mg/kg

Finally, considering the 11 component material categories of which the fertilizers may consist, they are classified into one of the 7 **Product Function Categories (PFC)**: Fertilizer, liming material, soil improver, growing medium, agronomic additive, plant biostimulants and fertilizing product blend.

Heavy metal contents are defined for all PFC limits, for example cadmium (Cd), chromium (Cr), mercury (Hg), nickel (Ni), lead (Pb), arsenic (As), copper (Cu), and zinc (Zn), and are formulated depending on PFC minimum requirements for hygiene (salmonella, e. coli), dry matter content or carbon and nutrient content.

	Cd	CrVI	Hg	Ni	Pb	As	Cu	Zn
	[mg/kg DM]							
Limit value	1,5	2	1	50	120	40	300	800

Furthermore, the absence of salmonella spp. has to be guaranteed for organic fertilizer, and the value of escherichia coli or enterococcaceae is limited by a maximum of 1000 colony forming units (CFU)/g.

There are two possible product function categories that digestate can be assigned to: on the one hand, it can be assigned to the PFC “fertilizer” and, on the other hand, to PFC “soil improver”. All nutrient contents are related on the fresh matter content. In most cases, digestate does not reach the required nutrient contents and, therefore, cannot be classified as “organic fertilizer”. Additionally, digestate will not fulfil the dry matter content in order to be part of solid fertilizers or soil improver unless the digestate is further upgraded. Specifically, this means the exclusion of the majority of digestate from the EU Fertilizer Regulation. This leads to a big disadvantage for the digestate market and, in the best case, should be changed.

This **inevitably results** in the necessity of upgrading for most liquid digestate (see Chapter 6: “Digestate upgrading techniques”) if they are to be marketed freely within the European Union. Of course, the requirements for national law remain unaffected by this, if the fertilizer is only to be marketed and applied inside one member state for which it meets the requirements. However, once the EU Fertilizer Regulation enters into force, national guidelines

Suggested heavy metal contents for organic fertilizer in [mg/kg dm]

	Solid Organic Fertilizer	Liquid Organic Fertilizer	Organic Soil Improver	Average of liquid digestate
DM-Content [%FM]	≥40	≤40	≥40	6
Nitrogen (N) [%FM]	2,5	2	-	0,3
Phosphorus (P ₂ O ₅) [%FM]	2	1	-	0,1
Potassium (K ₂ O) [%FM]	2	2	-	0,14
Organ. Carbon (C org) [%FM]	≥15	≥5	≥7,5	1,5

may also have to be amended and existing national standards adapted if necessary. The EU Fertilizer Regulation is not expected to come into force before the end of 2019.

In the Federal Republic of Germany, the **Fertilizer Ordinance** complies with the EU Fertilizer Regulation at the national level.

It specifies **constitution of the fertilizer**, e.g. which substances can be used, limit values on heavy metals and other pollutants, relevant nutrient contents as well as requirements on labelling and marketing. The planned application determines the classification as fertilizer, soil improver or growing media.

As a second requirement, the **Fertilization Ordinance** regulates good professional practice in the **application of fertilizers** on agricultural land. The requirements for upper application limits, determination of nutrient demand of the plant, nutrient surpluses, blocking periods, and storage capacity for storing organic fertilizers were significantly tightened by the last amendment for agricultural holdings. In doing so, the main aim is to implement the require-

ments of the European Nitrates Directive, which intends to avoid nitrate contamination of groundwater and surface water by agriculture. Restrictions on the application of nitrogen and phosphate-containing fertilizers depending on location and soil conditions are also laid down in the Fertilization Ordinance. The farmer must determine the **nutrient demand** for each crop or management unit before applying the digestate containing significant quantities of nitrogen and phosphate.

Probably the strongest intervention by the amended Fertilization Ordinance is the increase of the average **upper limit of 170 kg N/ha** to all organic and organic-mineral fertilizers, which means that digestate is now also affected independently of the input materials to produce it. This limit applies irrespective of the actual nutrient demand of the crop and regional characteristics, such as soil quality, yield expectations and the proportion of grassland. This regulation thus undermines the sustainable nutrient cycles and promotes the use of mineral fertilizers, as this is not limited across the board. In contrast, organic fertilizers have to be transported to other regions or to other distribution channels.

Application of digestate with drag hose



4 Possible applications

Organic fertilization is an important source of plant nutrients and organic matter for humification. The nutrients that are present in digestate are partly mineralised in various forms and are partly in organically bound form. This leads to differences in availability over time compared to mineral fertilizers.

Thousands of farmers use the many advantages of organic fertilization for agricultural crops. Since using nutrients also depends on the application technique, the weather, and the fertilized crop, there may be greater fluctuations in the effect of organic fertilizers. The nutrient content of digestate varies depending on the feedstocks used. In addition, there are different compositions depending on the treatment (separation, drying, etc.) digestate has undergone. Therefore, when separating the liquid and solid fractions of digestate, the liquid fraction is more likely to contain ammonium (NH_4) and potassium (K_2O) while the solid fraction is more likely to contain phosphate (P_2O_5) and organic material.

For plant-appropriate **nitrogen fertilization**, regular examination of the digestate is, therefore, indispensable. In principle, such analyses show that liquid digestate often has a dry matter content of 4-6%, and 60-80% of the nitrogen is present as directly available NH_4 due to anaerobic digestion. This has an effect on the pH value of the digestate, which is higher than that of liquid manure (about 8), which increases the risk of gaseous ammonia losses. This must be counteracted with technical measures accordingly, (see Chapter 5: "Application techniques").

The nutrient composition of the digestate and the effectiveness of the nutrients are crucial for **fertilization planning**. This is, for example, prescribed in the German fertilizing regulation on the basis of a fertilizer requirement determination. The availability of nitrogen depends directly on the NH_4 content and the ratio of carbon to nitrogen (C/N ratio). Fertilizers with a narrow

C/N ratio (slurry, manure, liquid digestate) have a much faster nitrogen availability than fertilizers with a wide C/N ratio (compost, manure, solid digestate). The table "Ingredients in typical digestate" provides an indication of the possible nutrient compositions.

The **ammonium** present in the digestate can be regarded by the farmer directly in the year of application as **mineral available nitrogen**. This value is around 60% for liquid digestate. In addition, there is a proportion of nitrogen, which is organically bound, but which is mineralised (available) during the vegetation period. The availability of nitrogen bound in organic substance varies. A small proportion is mineralised relatively quickly and can be absorbed by the crops in the year of application. Nitrogen, which is more strongly bound in the organic substance, is mineralised very slowly. Depending on weather conditions and soil tillage intensity, release rates of 1-3% of total nitrogen per year are to be expected.

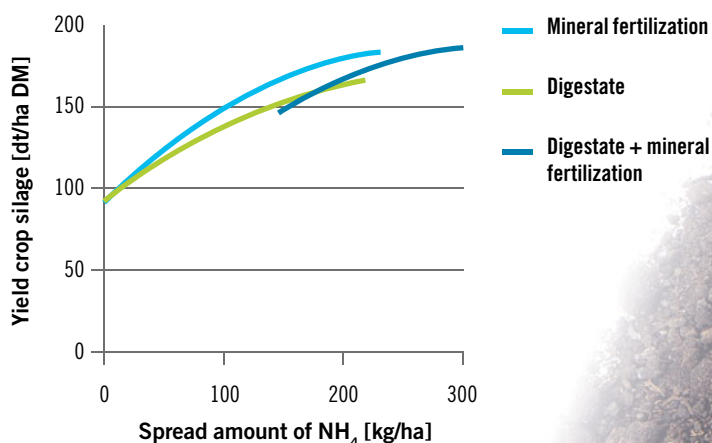
The German Fertilization Ordinance exemplifies how this continuous release of nutrients is incorporated into legal requirements. In the case of digestate, an effectiveness of at least 50% of the total nitrogen content applied is specified; for solid digestate only 30%. In addition, subsequent delivery from the previous year in the amount of 10% of the total nitrogen applied in the previous year must be added. The background to this requirement is that a continuous supply of organic fertilizers leads to an accumulation of humus in the soil with the consequence of a slowly increasing release of nitrogen. The following example illustrates this:

Ingredients in typical digestate

Form of digestate	DM [%]	N_{total} [kg/m ³]	NH_4 [kg/m ³]	NH_4 share [% of N_{total}]	P_2O_5 [kg/m ³]	K_2O [kg/m ³]
Liquid digestate	6.5	5.1	3.2	62.7	2.3	5.5
Liquid separated fraction	5.7	4.9	3.1	63.3	2.0	5.4
Solid separated fraction	24.3	5.8	2.7	46.5	5.0	5.8

Data from Bayerische Landesanstalt für Landwirtschaft

Yield effect of digestate



Data from Bayerische Landesanstalt für Landwirtschaft

If a farmer applies 30 cubic metres (m³) of liquid digestate with a nitrogen content of 5 kg N/m³ on his surface area every year, 50% of the total nitrogen applied (150 kg N/ha), i.e. 75 kg N/ha, can be directly credited. In addition, another 15 kg N/ha are added due to the 10% subsequent delivery from the previous year. In total, the farmer must or can count 90 kg N/ha from the organic fertilization.

As a rule, the NH₄ content is not to be regarded 1:1 as a mineral fertilizer equivalent. Tests have shown that not all NH₄ applied via digestate is equivalent to mineral fertilizer. Losses in spreading and sub-optimal soil conditions may be responsible for this. These yield disadvantages can be compensated for by combining organic fertilization with mineral fertilization. All in all, digestate is suitable for nitrogen fertilization in line with demand, but it also requires targeted use promptly in line with plant requirements (see illustration: "Yield effect of digestate").

The **phosphate and potassium quantities** contained in the organic fertilizers are equivalent in effect to those of mineral fertilizers in the long term and are therefore to be applied at 100%. Practice has shown that P₂O₅ is often the limiting factor for plant nutrition and requires a limitation of the application rate. In most cases, the usual mineral P-fertilization (e.g. underfoot fertilization for maize) can be restricted in the case of long-term organic fertilization. Based on the properties shown, typical application times and quantities can be derived in practice, which are shown in the following application example:

For grain silage with a nutrient demand of 190 kg N/ha, a digestate feed that covers a nutrient demand of 80–100 kg N/ha is typically suitable. With an effectiveness of 50% and an N content of 5 kg N/m³, this corresponds to a digestate quantity of just under 32–40 m³/ha. For high-yielding maize with a nitrogen demand of 220 kg N/ha, this administration could be combined with a later administration of about 15 m³ from the point of view of plant nutrition. This would cover a further 40 kg of the plant's nitrogen requirements.

Digestate contains not only nutrients but is also a **humus fertilizer**. During anaerobic digestion, the easily digestible carbon compounds are broken down, which would quickly mineralise the soil in any case thus not contributing to the build-up of humus. The stable carbon compounds contained in the digestate, on the other hand, sustainably enrich the humus content in the soil and generally have a higher humus reproduction capacity than undigested manure. If the digestate is separated, the humus-forming fraction is mainly in the solid fraction.

5 Application techniques

In contrast to mineral fertilizers, organic fertilization requires greater technical effort in order to actually supply the plant with nutrients. Losing them into groundwater and air must be minimised.

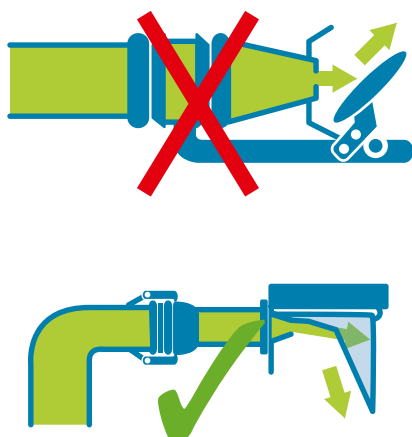


The high NH_4 content in conjunction with higher pH values carries the risk of losses in the form of **ammonia (NH_3)** during storage and application of the digestate. The risks can be minimised by low-loss application and immediate incorporation, which then result in an increase in the nutrient effect. The best possible use of nutrients is as the basis of the fertilizer value of digestate. If technical and organisational measures are observed, the NH_4 effect can be approximated by digestate to that of the effect of mineral fertilization.

Techniques for spreading liquid digestate that best meet the requirements mentioned above are processes with drag hose, drag or slit-shoe distributors as well as flat injection processes. Although a wide distribution allows for low-emission application, it is very weather-dependent. Good results can only be expected at cool temperatures in combination with subsequent rainfall. When choosing the technique, a crucial aspect is whether it is transferred to the stock or not.

The **wide distribution** by means of an upward deflecting baffle plate (see illustration: “Wide distribution”) was common for a long time and very susceptible to loss. It

Wide distribution



Wide distribution

has been banned in Germany since 2016. As a cost-effective spreading technique, an impact element is still permitted, which guarantees a horizontal or, better, downward-directed spreading of the digestate. This makes it possible to keep NH_3 losses low in comparison. Nevertheless, the distribution accuracy suffers from external weather conditions, especially wind. Immediate incorporation into the soil is essential, especially at warm temperatures. The advantage of this technology is – in addition to the affordable purchase price – the potential application in growing stock and on grassland as well.

A significantly better lateral distribution and lower NH_3 losses during spreading are achieved by attaching **drag hoses** to a linkage, which means that the digestate is fed directly to the soil at regular intervals. Thanks to the simple technology and the light-weight, large working widths, high-



Drag hose

power output can be achieved. Since no pressure is exerted on the hoses, the digestate is partly deposited on plants in growing crops or on grassland, which can lead to damage to the plants in unfavourable weather conditions.

In addition to spreading with drag hoses, the use of **drag or slit-shoe distributors** is particularly suitable for existing crops. Pressure is exerted on the ground here by means of the attached steel springs. However, this should not be confused with an injection that requires much more ground pressure. The soil skids on the underside of the tractors open the crop and easily break up the soil (depending on the type and density of the soil), which favours infiltration of the digestate into the soil. At the same time, damage to the plants and the grass cover is largely prevented. Direct ground contact also reduces the potential for loss. However, the technical effort is higher and is noticeable in terms of weight and capital expenditure.

The **injection with slitters**, in which the digestate is introduced directly into the soil, is optimal with regard to losses and thus also plant availability. This procedure is also possible in the growing stock. In grassland in particular, the danger of excessive damage to the grass cover can be seen here. A method frequently used in biogas plants is underfoot fertilization by injection prior



Injection with slitler

to maize sowing as a nutrient depot. Due to the complex technology and the great need for tractive power, such systems are mainly used on an inter-company basis and as self-propelled vehicles.

A variant of the slitler is called the **slurry cultivator**, where the digestate is spread and mixed with the soil in one operation. As with the slitting unit, this technology requires higher investments and enables comparatively small working widths. The liquid manure cultivator can only be used in uncloaked fields, which require different application techniques compared to growing crops. At the same time, it is in direct competition with drag hose application and subsequent incorporation with the conven-

tional cultivator. The farmer, therefore, has two options: one pass with a small working width or two passes with a large working width? The criteria have again been listed in the figure "Properties of the different application techniques".

The **technique for spreading solid or separated digestate** is carried out by the universal manure spreader. Systems with vertical or horizontal rollers are available. These spreaders can also be used to spread dried and pelletised digestate.

In addition to the application technique, **organisational measures** can also contribute to achieving optimum nutrient utilisation. As previously mentioned, immediate incor-

poration is urgently required on non-grown soils. On grown soils, **weathering** also plays a major role in preventing NH_3 losses if the digestate is not introduced directly into the soil. Cool, humid conditions are ideal, followed by rainfall.

The NH_3 loss potential correlates with the pH value. One way to reduce it is to **reduce the pH value** by acidifying the digestate. Here, for example, ammonium sulphate solution with a pH value of about 5 can be used, which generally occurs in some treatment processes. Alternatively, sulphuric acid can be used. This method is also used in various digestate treatment processes to minimise emissions during the treatment and storage of dried digestate in particular. Digestate has a higher NH_4 content, which is converted to nitrate in the soil over time. This can lead to the loss of this nitrogen during periods of greatly reduced nutrient uptake by plants. In order to avoid this and to allow early "reservoir fertilization", nitrification inhibitors (e.g. Piadin) can be used to slow down these conversion processes. An example of such storage fertilization is the previously presented underfoot fertilization before planting maize, in which a digestate depot is deposited in the soil.



Slurry cultivator



Spreading solid digestate

Properties of the different application techniques

Criterion	Technology				
	Wide distributor	Drag hose	Drag or slit-shoe	Injection with slitters	Slurry cultivator
Working width	++	++	0	-	-
Weight	++	+	0	-	-
Distribution accuracy	-	+	+	++	0
NH_3 losses	-	0	+	++	++
"Fertilizing effect"	-	+	+	++	++
Investment requirement	++	+	-	--	--
Contamination growth	-	-	+	+	No evaluation
Grass cover damage	+	+	0	-	No evaluation
Application area	Well-suited for self-mechanisation	Well-suited for self-mechanisation	Frequently only between different farms	Frequently only between different farms	Not applicable with vegetation
Note	Only good effect with good basic conditions or direct incorporation				

Data from Bayerische Landesanstalt für Landwirtschaft

6 Digestate upgrading techniques

Further upgrading and conditioning are important ways of saving storage, transport, and application costs. Upgrading can be the way to non-agricultural marketing, particularly in regions where the digestate cannot be fully applied in liquid form.

When additional storage capacities have to be created or digestate has to be transported over long distances, many operators of biogas plants consider investing in digestate upgrading. In addition, the idea of being able to establish new marketing channels, e.g. for private gardeners, garden and landscape companies, soil works and fertilizer manufacturers, plays an ever-greater role. But before the **choice of treatment method** can be made, the exact target should be defined. For example, is it generally possible to use digestate as fertilizer or is a complete treatment up to the discharge into water bodies necessary? Or is it only important to reduce the quantity and thus the water content in the digestate? Is excess heat from the biogas plant available for this treatment? Or should appearance and handling be optimised, because sales to other farmers have declined due to the competitive situation with other organic fertilizers? Is phosphorus or the nitrogen content a limiting factor for the application due to legal requirements?

The decision on the best process very much depends on the individual plant concept and regional conditions and cannot be made across the board. Furthermore, the individual processes are evaluated according to goal, technology, energy and equipment requirements, which can vary greatly from manufacturer to manufacturer and sometimes also differ from the information provided. The upgrading technologies presented in this publication are merely intended to provide an initial assessment and an overview of the various options.

The first treatment step is usually **separation** into a liquid, pumpable, and a solid, stackable fraction. Two different products are already created here, which can be used in very different ways. The solid fraction is lower in nitrogen and K_2O but enriched with P_2O_5 . It can be used to build up humus mainly because of its higher carbon content. The transport worthiness also increases with increased DM content. Since phosphate also often limits the use of digestate, the liquid separated fraction with a relatively lower P_2O_5 content can be used better in relation to the nitrogen requirements of the crop to be fertilized.

The **evaporation** and the **membrane filtration** (mostly ultrafiltration and reverse osmosis) are available for dewatering and thickening the liquid fraction. There is also increasing interest in processes such as **stripping** and **precipitation** or in the recovery of ammonium sulphate solution from liquid digestate. Ammonium sulphate solution can also be obtained in an acid scrubber after drying or vacuum evaporation. By removing water, the necessary storage capacity can be reduced, which must be maintained in cold countries if fertilization is no longer required in late autumn and winter.

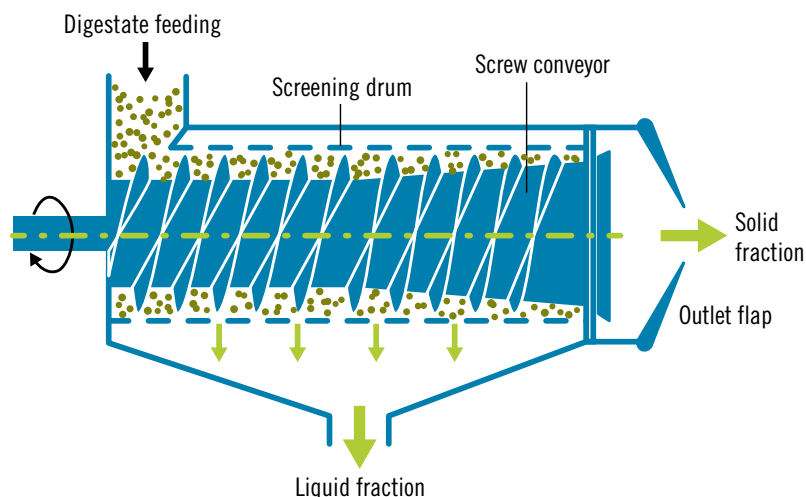
The **drying** of the solid fraction and, if necessary, the **granulation** or **pelletisation** of the dried digestate are well established techniques. The focus here is on improving the appearance, handling, storage suitability, and marketability. During pelletising, the individual nutrients or other mineral and organic additives obtained from the liquid fraction can be added in order to be able to offer fertilizers as required by the customer. This is an interesting perspective for a future market for fertilizers that can be produced from digestate.

Especially with the digestion of municipal biowaste, **composting** is carried out downstream in many countries. Marketing composts is established in many countries and the application leads to a very high humus supply. In some cases, the liquid digestate from these plants is introduced into **waste water treatment plant (WWTP)** together with municipal waste water by converting the nitrogen contained into atmospheric nitrogen N_2 (see Chapter 6.4: "Biological treatment") and thus is no longer available as nutrients.

In any case, the goal should be **responsible optimisation of nutrient management**, which can certainly be associated with a reduction in costs or increase in added value. A sustainable decision should, therefore, also be made with regard to NH_3 emissions from the individual processes, which can be implemented by appropriate technologies, such as acid scrubbers. The ammonium sulphate solution produced can then be used agriculturally as mineral fertilizer or marketed externally.

6.1 Separation

Screw press



The **goal of separation** is to mechanically separate the digestate into a liquid and solid fraction. There is no reduction in volume; only the need for storage tanks for liquid digestate is reduced by around 10-20% by separating the solid fraction, depending on the composition of the starting materials and separation technology. Separation is usually the first step before further processing.

The stackable **solid fraction** with a DM content of 20-40% is more cost-efficient in terms of transportability. Above all, carbon and phosphate are enriched, which means that solid digestate is suitable as good phosphorus and humus fertilizer for catch crops and main crops with long growth cycles.

The **liquid fraction** with a DM content of 1-8% has high flowability and can, therefore, easily drip off the plant and enter the soil. Due to the enrichment of NH_4 , this fraction is a fast-acting nitrogen fertilizer that is immediately available to plants (e.g. maize, cereals, rape seed, grassland).

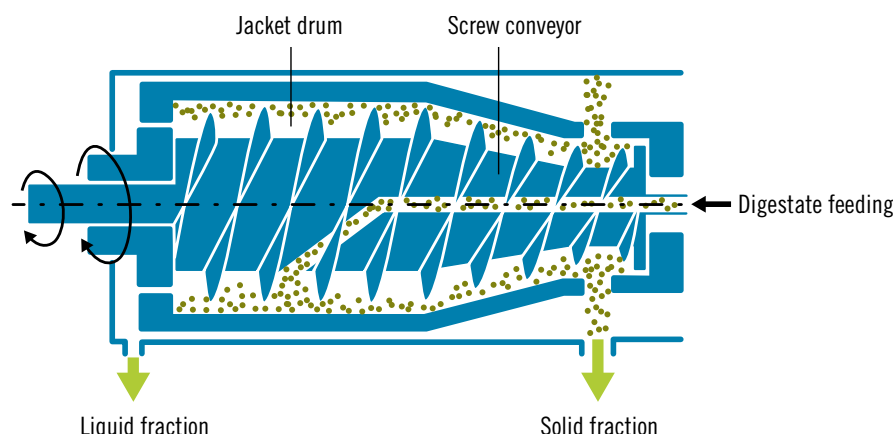
The **screw press** is the most commonly used technique. This is when a rotating screw conveyor which sits in a screening drum presses the digestate against an outlet flap from which the solid fraction can exit. The liquid fraction is separated by the screening drum with a defined hole width of 0.5-1mm. Contact pressure, hole width, and back pressure of the outlet flap determine the degree of separation. The technology is mature, robust, and simple. The power consump-

tion is between 0.2-0.6 electrical kilowatt hours per cubic metre ($\text{kWh}_{\text{el}}/\text{m}^3$) input, depending on version and size.



Screw press

Decanter



Second is the **decanter** (the centrifuge), in which a fast rotating screw conveyor is located in a slower rotating jacket drum. Due to the higher density and inertia, the solid digestate is pressed against the jacket drum and transported away. The liquid fraction can exit between the screw conveyor and the jacket drum. The degree of separation can be varied via the speeds of the screw conveyor and the jacket drum as well as via the throughput. The centrifuge has a very high degree of separation. The power consumption is $2\text{--}5\text{ kWh}_{\text{el}}/\text{m}^3$ input.

In **belt filter presses**, the digestate is compressed as wedge-shaped between two filter belts and water is pressed out through the belts. The belts are guided via deflection rollers, thus gradually increasing the pressure. The degree of separation can be adjusted via the contact pressure, running speed, and condition of the

filter belts as well as the number of deflection rollers. Flocculants are usually added. The power consumption is $1.5\text{--}5\text{ kWh}_{\text{el}}/\text{m}^3$ input.

Furthermore, **screens** (e.g. a vibrating sheet or drum screens) for the separation of solids (or impurities) can also be used in combination with the aforementioned techniques. The liquid fraction can flow off through the screens and the solid fraction is retained and transported to the outlet. The degree of separation is set via the hole width, the angle of inclination, and the frequency of rotation or vibration.

Flotation takes advantage of the effect that particles adhere to rising air bubbles and can float with them. Air-enriched liquid is introduced into the flotation tank for this with the addition of flocculants. A flotation sludge forms on the surface of the basin where it can be skimmed off. The advantage of flotation is the very pure, almost particle-free liquid fraction, which can be easily used in membrane filtration, for example. The flotation sludge has a very high-water content and may have to be thickened further. The power consumption is about $0.2\text{ kWh}_{\text{el}}/\text{m}^3$ input.

In order to achieve higher solids separation, **floc-culants** can be used in the presented methods as flocculants or flocculation aids. This creates an agglomeration of the particles contained in the digestate and thus considerably improves the separation. The addition of flocculants is associated with further expenditure, but may be necessary in certain cases, e.g. with a very low DM content of the digestate to be separated or if a particle-free liquid fraction is required for further processing.



Decanter

6.2 Drying

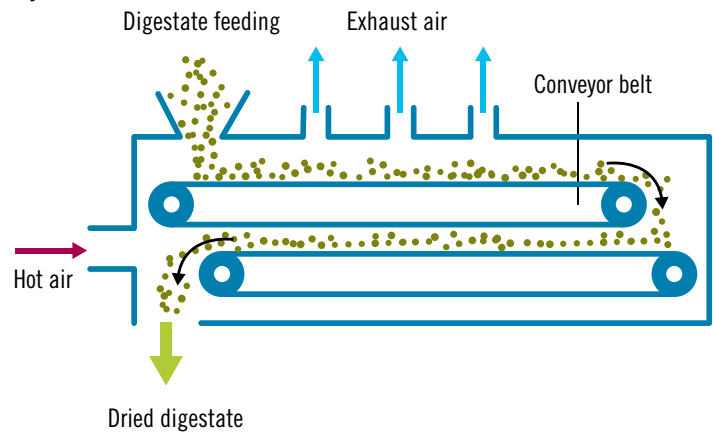


The **goal of drying** is to evaporate water and produce dried digestate (for evaporation of liquid digestate, see Chapter 6.5: “Liquid preparation”). The hot air, e.g. from the CHP of the biogas plant, is conducted through or over the digestate to be dried. The products can be transferred to new sales areas such as earthworks or fertilizer production or used as bedding in animal stables. The thermal use of dried digestate has not yet been really established due to technical difficulties such as high ash production, NO_x emissions, and concentration of heavy metals. The various drying processes are technically mature and are established in Germany due to additional support for heat utilisation (for the potential fire hazard of the dried digestate and dryers see Chapter 10: “Safety first!”).

For **dried digestate**, the desired DM content (up to over 90%) can be set via drying time and temperature. Depending on the residual moisture, they are stable in storage and transport, but may have to be compacted further to avoid dust emissions and spontaneous combustion and to decrease transport costs (see also Section 6.3: “Pelletising”). Alternatively, dried digestate might be mixed back into the liquid starting fraction to produce granulates during drying.

To avoid NH₃ emissions, the exhaust air from the drying process should be cleaned with an acid scrubber with the production of **ammonium sulphate solution** at the same time. Alternatively, NH₃ emissions can be avoided by acidifying the digestate before drying.

Belt dryer

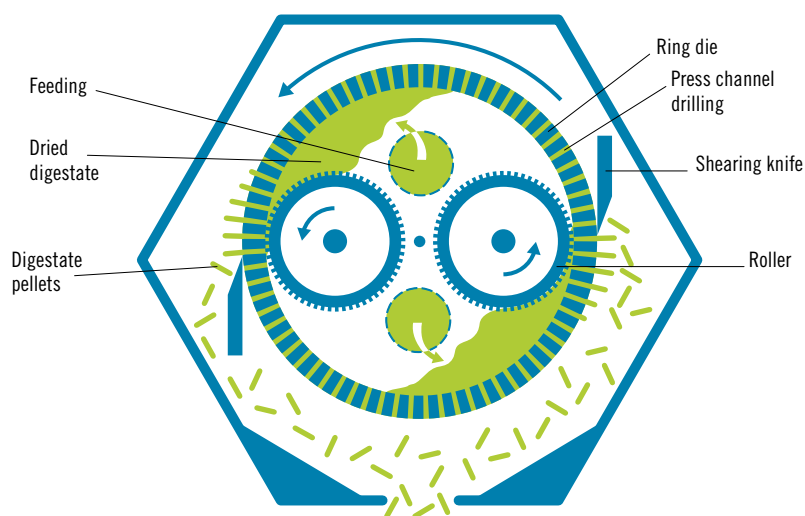


Most frequently, **belt dryers** are used (see illustration: “Belt dryers”) in which the digestate is placed on a conveyor belt and dried at temperatures of 60-150°C for about 2 hours. Multiple bands can also be arranged one above the other. A similar principle applies to **push-turn, fluid bed, and drum dryers**, in which the digestate is transported through the hot air by movement of vanes, air injection, or a rotating drum. With **trailer or container dryers**, hot air is blown through a motionless pile. In **solar-assisted drying**, the digestate is distributed on the floor of a large greenhouse and rearranged by a self-propelled turning trolley. Warm air at around 40°C is blown onto the digestate layers by fans. Drying is supported by solar radiation into the greenhouse. Depending on the technology used, the heat requirement is 750-1,200 kilowatt hours of thermally evaporated water per cubic metre (kWh_{therm}/m³H₂O).



Solar-assisted drying

6.3 Pelletising



The goal of pelletising is to compact the dried digestate into digestate pellets in order to improve the density as well as handling and appearance. This requires a DM content of the dried digestate of 85-90%. The digestate is pressed through dies under high pressure. This results in very high temperatures on the surfaces, which means that the digestate pellets melt on the outside and have a glassy shine.

In the **ring die**, the digestate is pressed from inside to outside through the annular die from inside rollers.

Alternatively, the digestate can be fed to a pair of hollow rollers and pressed into the interior of the dies or through a folding die of bollards above. The power consumption for pelletising dried digestate is about 30-50kWh_{el}/ton.

Loose dried digestate has a bulk density of 250-350kg/m³. Pelletising produces pellets with a bulk density of 700-750kg/m³ and thus considerably decreases transport costs and increases storage suitability.

The **digestate pellets** can be optimally marketed in smaller packages in garden centres and hardware shops. Because of their cleanliness, they are easy to use for the end customer. In addition, larger quantities can be sold in new spreading areas, such

as vineyards, where conventional spreading of liquid digestate is not common. The digestate pellets dissolve when exposed to moisture, which means that the nutrients contained are provided to the plant. At present, only a few biogas plants pelletise dried digestate and subsequently market it outside the agricultural sector, although the potential is estimated to be very high. Digestate pellets can additionally be refined to special fertilizers with mineral or organic additives.

Sale of digestate pellets in retail trade



6.4 Biological treatment

The **main goal of biological treatment** is to stabilise organic material with aerobic treatment or combined anaerobic and aerobic treatment. Odour emissions are reduced and nitrogen is fixed as bound organic nitrogen or converted into atmospheric nitrogen



With **composting**, solid digestate from dry digestion plants or from separation can be converted into compost by targeted aerobic rotting (addition of structural material, regular turning, and optionally aeration). They are subdivided into **fresh and matured composts** and are both soil additives and fertilizers accepted commercially, for gardening, landscaping work as well as for private customers. During rotting, the soluble nutrients and carbons contained are converted into more stable humus complexes. Due to the aerobic biological conversion processes, temperatures of more than 70°C arise, which means that post-composting of solid digestate from the digestion of municipal biowaste can be used as sanitation due to its germicidal effect.



Municipal waste water treatment plant (WWTP)



As implemented in municipal **waste water treatment plants (WWTP)**, the conversion of the nitrogen compounds contained in the digestate into atmospheric nitrogen (N_2) is also considered a biological process. This works by combining nitrification, an aerated (aerobic) conversion of NH_4 to nitrate, and denitrification, the anaerobic conversion of nitrate to atmospheric nitrogen (N_2). Larger tanks are usually necessary for this, which are used for ventilation, sedimentation, clarification, and if necessary precipitation. The aim is to then discharge the purified **water** into the receiving water bodies. Due to the surplus of nutrients in agriculture, processes based on these biological mechanisms of action have recently attracted greater interest, although in the past they were presented as nutrient elimination, as the circulation is interrupted here, and nitrogen for the production of mineral fertilizers has to be recovered from the air again at a great expense of energy.

Turning of compost windrows by means of wheel loaders



6.5 Liquid preparation

The **goal of liquid treatment** is to achieve a significant volume reduction (up to 50%) by separating the water. The solids or nutrients are concentrated in a viscous solution with a DM content of up to 15%.

Concentration can be achieved by thickening under normal pressure (**atmospheric evaporation**), in a closed system under negative pressure (**vacuum evaporation**), or by filtration in a membrane process. Prior separation is not imperative for atmospheric evaporation. However, it is for vacuum evaporation and the **membrane filtration**. These procedures are much more technically demanding and sensitive. They are established in water treatment and other industrial processes, for example. For processing digestate, on the other hand, they are less common but are currently enjoying great demand especially in Germany.

The concentrated **nutrient solutions** (concentrate) can be applied like liquid digestate, but the workload is reduced as less water has to be transported and more agricultural area can be fertilized in a shorter time. In addition, the necessary storage capacity is reduced and thus the costs for transporting the digestate are also reduced. The produced **water** (permeate) can be discharged into water bodies or the sewage system, or rained over agricultural land, depending on local requirements. The **ammonium sulphate solution** from the exhaust air treatment of atmospheric or vacuum evaporation can be used or marketed as mineral fertilizer. Alternatively, the pH value can be reduced by acidifying the digestate so that nitrogen is bound in the concentrate.



Atmospheric evaporation is similar to drying, with the difference that no dried digestate is produced, but instead thickened liquid nutrient solutions. The aim is to create the largest possible

surface for evaporation by distributing the liquid digestate over lamellas, filter belts, discs, and drums. The heat requirement is $1,000\text{--}1,500\text{kWh}_{\text{therm}}/\text{m}^3$ evaporated H_2O .

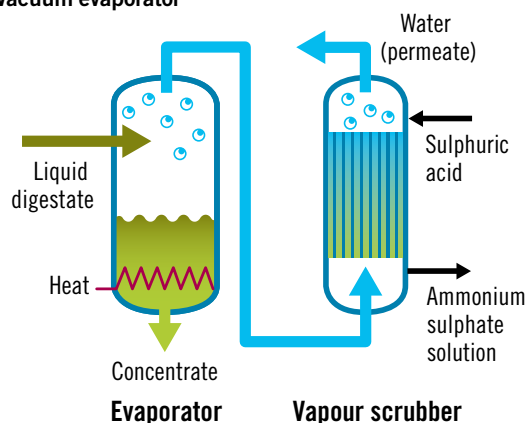


Vacuum evaporator

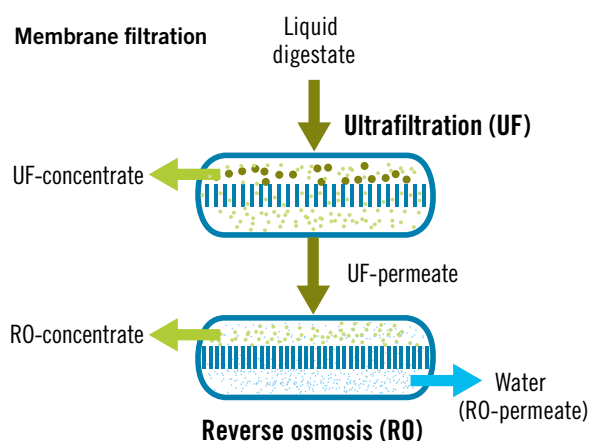


Vacuum evaporation occurs in a closed system which means that no exhaust air is produced. The liquid digestate is distributed in the inner surface of the evaporator, the internal heat plates, or the heat exchangers, e.g. by brushing or overflow. The reduced pressure reduces the boiling temperature to $40\text{--}75^\circ\text{C}$, which means that H_2O , CO_2 , NH_3 (with the pH value not reduced) leave the liquid fraction. This steam mixture is cleaned of acids and NH_3 in

Vacuum evaporator



a subsequent vapour scrubber and if necessary condensed. The power requirement is $10\text{--}13\text{kWh}_{\text{el}}/\text{m}^3$ input and the heat requirement is $600\text{--}1,000\text{kWh}_{\text{therm}}/\text{m}^3$ evaporated H_2O in a single-stage process. Several units are often connected in a series (multi-stage process) in order to use the heat from the steam mixture for the next stage. In the 4-stage process, the power requirement can be reduced to $5\text{kWh}_{\text{el}}/\text{m}^3$ input and the heat requirement to $250\text{kWh}_{\text{therm}}/\text{m}^3$ evaporated H_2O .



Modules of reverse osmosis



In **membrane filtration**, different membranes with decreasing pore sizes are usually used (micro, ultra, nanofiltration, and finally reverse osmosis). Ultrafiltration (UF) with a pore size of 0.01–0.05 micrometres (μm) and reverse osmosis (RO) with a pore size of 0.0005–0.005 μm are usually used for treating liquid digestate. Since membranes

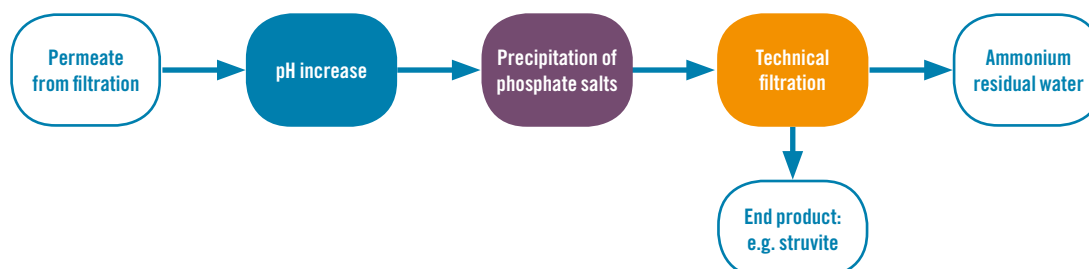
are very sensitive to solids, using flocculants in separation and/or flotation is usually necessary to produce a liquid fraction that is as particle-free as possible. With increasing clogging, the energy requirement rises sharply due to frequent cleaning intervals and the throughput decreases. The power consumption is between 10–30 $\text{kWh}_\text{el}/\text{m}^3$ input.

6.6 Nutrient extraction

The **goal of nutrient extraction** is to produce fractionated single nutrients that can be used as mineral fertilizers or in the chemical industry. In addition, the digestate is removed to the point where it can be discharged into water. At present, these processes are not very common when upgrading digestate. The upgrading steps for complete nutrient extraction include filtration, phosphate precipitation, and ammonium stripping.

In precipitation, **magnesium ammonium phosphate (MAP)** or **calcium phosphate salt** is obtained, which is used directly as a readily available mineral fertilizer or for further fertilizer production. In stripping, **ammonium sulphate solution** can be produced from the gas scrubber and, if necessary, a **nitrogenous lime fertilizer** as well. In addition, a nitrogen-reduced digestate is obtained, which can be recirculated to the digestion process. This nitrogen sink makes it possible to use higher quantities of nitrogen-containing feedstocks, such as dry poultry manure without biological inhibition. The wastewater with a high proportion of organic matter and nutrients can be spread like a liquid digestate or undergo further treatment.

Precipitation



The **precipitation** of the phosphate occurs from the liquid fraction, from which all solids must be separated. This is done through several filtra-

tion stages up to microfiltration with a pore size of $< 0.1 \mu\text{m}$. Increasing the pH value shifts the solubility equilibrium of the phosphates. Phosphate salts precipitate as



Precipitation

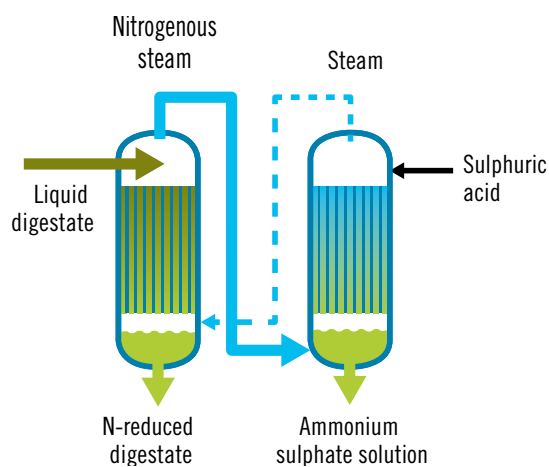
a solid. The composition of the phosphate salts can be influenced by the choice of caustic solution and additives. For example, adding magnesium struvite (MAP) causes precipitation to occur. The precipitated salt is filtered off

and can be used for producing fertilizers or in the chemical industry. The power consumption is about 10-15kWhel/m³ input, but the data is from first pilot plants and can probably be further reduced in larger plants.



Stripping

Stripping



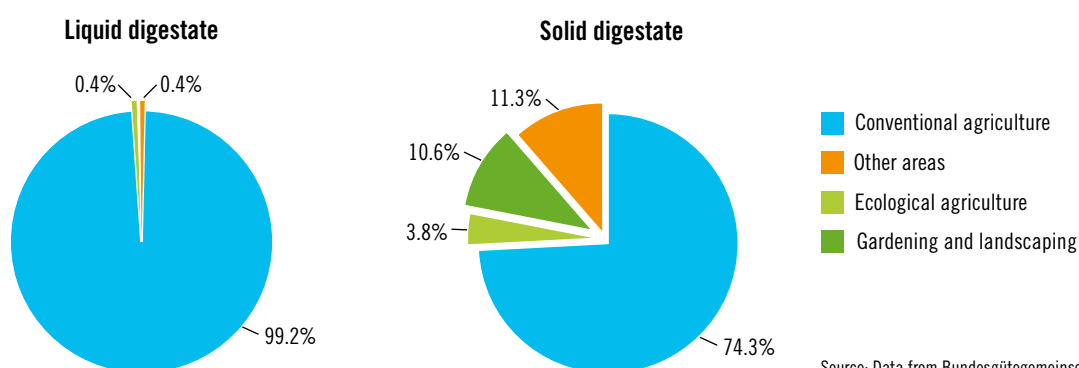
Stripping is used to reduce the ammonium nitrogen content of the digestate. To do this, the $\text{NH}_4^-/\text{NH}_3$ balance must be shifted to the ammonia side. This is achieved by increasing the pH value and the temperature. The input material is sprinkled in a column and gas is applied in counter-current. Depending on the process, the gas is either air or steam. Air stripping is less energy-intensive than steam stripping but requires more lye. The gas is loaded with ammonia and regenerated in a gas scrubber with the addition of sulfuric acid, where ammonium sulphate solution is produced. Alternatively, gypsum from flue gas desulphurisation (FGD gypsum) can also be used for regeneration, which additionally produces nitrogenous lime fertilizer. If the digestate is treated without

prior separation, lignocellulose fibres freed of NH_3 can also be produced and used as wood or fibre substitutes. Furthermore, the temporary temperature increase of the feedstock to over 70°C leads to further decomposition of the organic matter, which leads to an increased biogas yield. The ammonium can be completely removed by stripping phosphate-free permeate from the precipitate. Since the permeate is free of solids, usual problems such as blocking and overgrowth of the fillers of the stripping system do not occur. The resulting residual water has a chemical oxygen demand (COD) too high to be dischargeable directly into water and must be rained out or further purified accordingly. The power requirement is about 5–10kWh_e/m³ input and the heat requirement is 45–100kWh_{therm}/m³ input.

7 Marketing strategies

The operators of biogas plants have to make a number of marketing decisions for economically optimal use of digestate. The crucial factor is which target customer groups the digestate will be sold to. The design of the product, the sales channel, communication, and the price all depend on this.

Distribution of sales for digestate among customer groups



Source: Data from Bundesgütegemeinschaft Kompost e.V.

In Germany, thus far most biogas plants have been delivering their digestate untreated to farms, preferably to areas very near to the plant. This is particularly true for liquid digestate; other customer groups are increasingly being tapped for solid products (see graphs: “Distribution of sales of digestate among customer groups”). However, many plants have difficulties selling their digestate to farms nearby. The new fertilization ordinance will further exacerbate this situation. By upgrading the digestate into marketable fertilizers, plant operators can tap into new customer groups (see illustration: “Potential sales channels and customer groups”). Digestate marketing is also a relevant and important factor in other countries, when trying to make a biogas plant economically feasible (see Chapter 9: “Significance of digestate in developing countries”).

Each of these customer groups has different demands on the **design of the products**. The various products that can be produced from digestate were presented in detail in Chapter 6: “Digestate upgrading techniques”. For example, farms can use unprocessed digestate with a DM content of only 7%. Private gardeners, on the other hand, prefer solid products such as pellets or concentrated liquid products.

The **distribution paths** also differ. Farmers and processors such as earthworks are more likely to be served directly by the plant operators. Private gardeners, on

Processing digestate facilitates marketing on three levels:

- ▶ Concentration of nutrients increases the value per unit of weight and thus decreases the transport costs
- ▶ Upgraded products are easier to handle and smell less
- ▶ Upgrading, possibly coupled with the addition of nutrients and standardisation, taps into new sales markets (private gardeners) and new distribution channels (garden centres).

the other hand, usually buy their fertilizer products in garden centres or hardware stores. Moreover, direct delivery to private households via an online shop or the farm shop is also possible.

Last but not least, **pricing** shows large differences between customer groups. Agricultural businesses are partly geared to the fertilizer value of the digestate in their willingness to pay. Particularly in nutrient-rich regions, however, it is quite common for digestate to be supplied by plant operators free of charge or even with an additional payment to farmers. In contrast, the prices for private gardeners are several hundred times higher than in the agricultural sector. However, these prices must also cover the costs of processing, marketing, and sales.

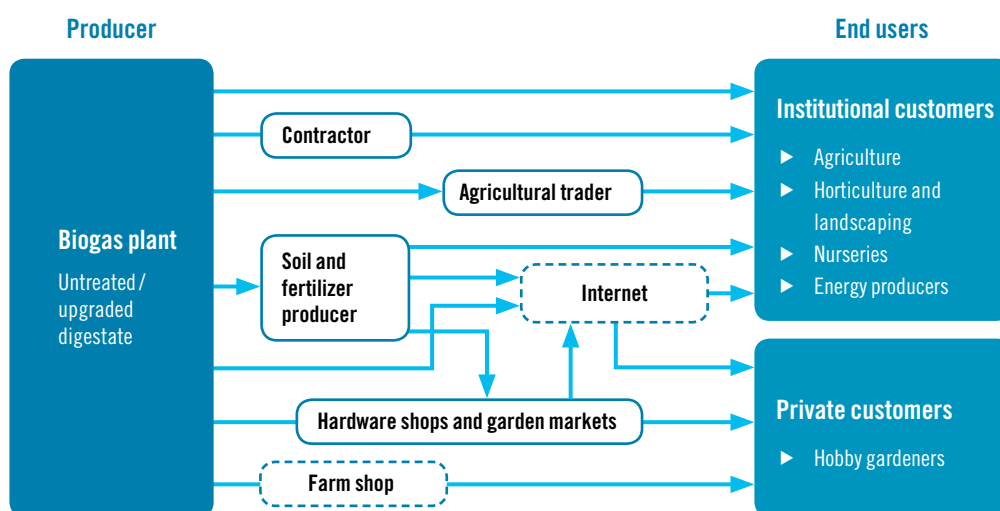
The **private gardener customer group** is an interesting target market. First, high revenues are generated in this sector: in Germany alone, almost 1.7 billion euros (€) were generated in 2015 for fertilizers, soils, and plant protection; the size of the total garden market in Germany is approximately 18 billion euros. In the entire EU, almost 90 billion euros are generated in the garden market, and in the USA alone, nurseries and garden centres generate total sales of over 40 billion US dollars. And second, the final prices are quite high: in some cases, up to €4/kg can be charged for branded products, a multiple of the nutrient value. However, the

- ▶ Determining the significance of different product attributes for the purchase decision from the choice decisions using statistical calculations

In the **qualitative interviews**, it quickly became clear that most private gardeners have uncertainties when buying fertilizers and soils. Many customers, therefore, take the product name (e.g. rose fertilizer) and the brand as factors when deciding what to purchase. The ingredients on the back of the packaging are also considered. For many buyers, however, this information is too complicated and not very meaningful. Some quotes

from the qualitative interviews with private gardeners are presented as examples.

Potential sales channels and customer groups



Customers still do not understand what their fertilizers are composed of. However, keywords such as “guano” were understood by those surveyed. In addition, “organic” is another important, positive criterion for some consumers. It is worth mentioning that fertilizers and flower and flowerbed care products are mainly purchased by women. Another interesting result is that consumers differentiate greatly in some cases when it comes to fertilizing: Organic

integration of digestate in this sector depends on the acceptance of fertilizer manufacturers, retailers, and end customers. The preferences and attitudes of private gardeners towards garden fertilizers are, therefore, crucial and important criteria for marketing digestate in the horticultural sector.

fertilizers are preferred for vegetable cultivation, whereas mineral fertilizers are used for ornamental and pot plants because they are not consumed.

A study on **how private gardeners make decisions** was conducted in Germany as part of the **GÄRWERT project**¹ by Nuertingen-Geislingen University and Kantar TNS:

- ▶ Pre-study: 20 qualitative interviews with private gardeners, evaluation by means of qualitative content analysis
- ▶ Large-scale online survey with a total of over 1,000 participants, quantitative analysis
- ▶ Questions on attitudes and socio-demography
- ▶ Choice experiments: Participants were presented with different fertilizers and soils and had to choose between three products in twelve rounds (discrete choice experiment)

Stinging nettle is a very good fertilizer: it keeps away vermin and is said to act as a growth accelerator. You also hear that it was sometimes banned because it is so good, and because it is not necessarily... desired by the industry, etc. I think it's already banned in France

2

Some of the preferences mentioned regarding the possible starting materials in the digestate are contradictory: Energy crops were generally evaluated rather negatively. The digestates from it, on the other hand, were appreciated for their homogeneity for possible use in the garden. In contrast, private gardeners saw the risk of unpleasant residues and impurities in digestate from waste digestion plants, although they generally assessed waste plants positively for ecological reasons.

¹ We would like to thank the Fachagentur für Nachwachsende Rohstoffe e.V. (FNR) and the Federal Ministry of Food and Agriculture (BMEL) for funding the GÄRWERT project (FKZ: 22402312).

The results of the online survey provide further insights into consumers' decision-making behaviour. The colours in the tables indicate how important the respective attribute is for the respective buyer group. However, they do not specify which attribute levels (e.g. high or low prices) are preferred by the gardeners.

My mother was given this tip once. They once had a lodger whose brother or father had had a nursery, and he said the best thing for tomatoes is cow dung

The first table shows the results of the choice experiment for fertilizer and shows that the significance of the product properties for the different customer groups varies to a large extent. Groups 2 ("Price-sensitive green buyers") and 3 ("Price-sensitive buyers") pay almost exclusive attention to low prices. Group 5 ("Premium product buyers"), on the other hand, is very brand-conscious, but also takes other properties into account, e.g. whether the fertilizer is "organic". It is interesting that for Group 5 a higher rather than a lower price encourages them to buy. This group apparently uses price as a quality indicator. It is also worth noting that for all customer groups, with the exception of the "price-sensitive" ones, the "organic" property is of medium importance, which offers starting points for the marketing of digestate. Whether the fertilizer is mineral or organic, on the other hand, only plays a role

for "premium product customers". The overall nutrient content is also of little importance; most customers do not know the meaning of the values.

The results from the choice experiment on the soils shown in the second table also show clear differences between the customer groups. Group 3 ("Eco-product buyers") should be the most interesting group for digestate marketers. These customers place great importance on the raw material of their garden soils and respond positively if they originate from energy crops. This customer group can also be won over by the fact that digestate could be declared peat-free and in some cases as "organic". Group 4 ("Premium product buyers") also places importance on raw materials and being peat-free. Another attractive feature of this group is that it prefers high prices. Here, too, the price seems to serve as a quality indicator. Group 5 ("Pure price buyer") buys almost exclusively according to price and is rarely interested in raw materials or whether it is peat-free.

My father has always fertilized with blue grain, and my wife's grandfather has always fertilized with horn meal.

The brand plays only a subordinate role for all groups with respect to soils. As far as raw materials are concerned, the phrase "from energy crops" is extremely popular across all customer groups, but the claims "from digested residues" and "from residues of a biogas plant" are far behind. When using guano, the buyer groups have different preferences: Group 1 avoids guano, Group 4 on the other hand sees guano positively.

² Quotes from the qualitative interviews with private gardeners

Significance of product attributes for different customer groups (fertilizers)

n=504	Group 1 (n=53) "Universal product buyers"	Group 2 (n=36) "Price-sensitive green buyers"	Group 3 (n=96) "Price-sensitive buyers"	Group 4 (n=273) "Multi-criteria buyers"	Group 5 (n=46) "Premium product buyers"
Brand (premium fertilizer/cheap fertilizer)					
Organic (yes/no)					
Nutrient content (NPK)					
Organic/mineral					
Price (€6, €9, €12)					

Significance of product attributes for different customer groups (soils)

n=507	Group 1 (n=55) "Raw material sensitive buyers (anti guano)"	Group 2 (n=148) "Price-sensitive buyers"	Group 3 (n=61) "Eco-product buyers"	Group 4 (n=116) "Premium product buyers"	Group 5 (n=127) "Pure price buyers"
Brand					
Label (organic)					
Label (peat-free)					
Label (with guano)					
Raw material					
Price (€4, €6, €8)					

low significance
medium significance
high significance

A conclusion can be drawn that there are indeed buyers among private gardeners for whom product properties evident in digestate are very important: Origin from energy crops, peat-free, and the “organic” label. This market should, therefore, be given greater consideration in the future. The results from Germany cannot be transferred 1:1 to other countries. Knowledge of fertilizers as well as preferences can differ considerably. But the German data can be used as an initial point of reference for marketing or their own consumer studies. The following aspects are particularly important for marketing:

Product policy

- ▶ The product name (bush fertilizer, rose fertilizer, tomato fertilizer, etc.) is of great importance when buying, as it has a recommending effect, although the fertilizers do not have to meet any requirements regarding certain NPK contents.
- ▶ The nutrient content, on the other hand, is meaningless for many buyers.

Price policy

- ▶ Demand for low and medium-priced products is the highest.
- ▶ However, there are also customer groups that use price as a quality indicator.

Communication policy

- ▶ Labels such as “peat-free”, “organic”, and “from energy crops” can be decisive for certain groups.

However, there is no doubt that a broad product range with special fertilizers and differentiated marketing exceed the options of many plant operators. Partners should, therefore, be sought in the retail business or among fertilizer and soil manufacturers. Another idea is for biogas plants to be merged into a joint marketing venture.



8 Quality assurance in Europe

Quality assurance schemes for compost and digestate products have been established in several EU countries over the past 25 years. They form the backbone of sustainable recycling of bioresources, ensuring that quality products are manufactured consistently and placed on the market with high quality.

In order to support the manufacture of quality compost and digestate across Europe, The European Compost Network e.V. (ECN) developed a concept for a pan-European quality assurance scheme (ECN-QAS) within its working group “Quality Assurance and Standardisation”. This includes the characterisation of quality standards for recycled organic resources (compost and digestate) with the aim of facilitating the free cross-border movement of goods within the EU. It is based on existing national quality assurance systems and knowledge within member organisations. The ECN-QAS is registered as Trade Mark for certified quality assurance organisations, compost and digestate products at the European Register of Community Trade Marks (‘OHIM 2012/210: TM No 011007168’).



Trade Mark ‘ECN-QAS’

The ECN-QAS, which was launched in 2010 and amended with quality criteria for digestate in 2014, sets out requirements for national quality assurance organisations, process management and compost and digestate quality criteria. Its aim is to set a common basis for existing quality schemes in Europe and to support member states in defining quality standards and developing their own quality assurance schemes for composts and digestate. At present, four national quality assurance organisations (in Austria - KBVÖ, Belgium - Vlaco, Germany - BGK and Italy - CIC) have been approved.

The ECN-QAS has supported European policy initiatives setting end-of-waste criteria for compost and digestate within the Waste Framework Directive and was cited in the JRC-IPTS report on End-of-Waste criteria for compost and digestate: *“the European Compost Network has established a quality management system for compost, which is widely supported.”*

The ECN-QAS provides a European-wide independent quality assurance scheme for national quality assurance organisations (NQAO). It operates in accordance with the ISO/IEC standard “Conformity assessment for bodies certifying products, processes and services” (ISO/IEC 17065) and has been based on knowledge of, and experience in, existing quality assurance organisations. The ECN-QAS requires:

- ▶ a conformity assessment of the national quality assurance schemes by ECN;
- ▶ regular assessment of compost and digestate production in the plants by the national quality assurance organisation;
- ▶ regular sample taking and analysis of the final product for relevant quality parameters from independent, acknowledged laboratories, coupled with evaluation of the results by the national quality assurance organisation;
- ▶ documentation by the national quality assurance organisation with information about the quality properties of the product, legal requirements, the necessary compost and digestate declaration and information about use and application rates according to good practice;
- ▶ awarding of the ECN-QAS Quality Label to composting or digestion plants by the certified national quality assurance organisation.



ECN-QAS labels for compost and digestate

Information about the ECN-QAS and the ECN-QAS Manual can be accessed through the dedicated website: www.ecn-qas.eu.

9 Significance of digestate in developing countries

Strategies for agricultural development in developing countries – leading to economic development – need to be geared towards affordably increasing sustainable productivity of land under cultivation. Digestates enter this discussion in promoting a healthy soil-plant-environment system, with aspects like increasing organic matter in the soil and water holding capacity toward reducing land degradation and improving sustainable agricultural production.

According to the prevalent definition, a **developing country** is considered a country with a less developed industrial base and a low Human Development Index (HDI) relative to other countries. Developing countries include (in decreasing order of economic growth or size of the capital market): newly industrialised countries, emerging markets, frontier markets, and least developed countries. Therefore, the least developed countries are the poorest of the developing countries. The vast majority of developing – and especially least developing – countries are on the African continent (see illustration: “Least developed countries”).

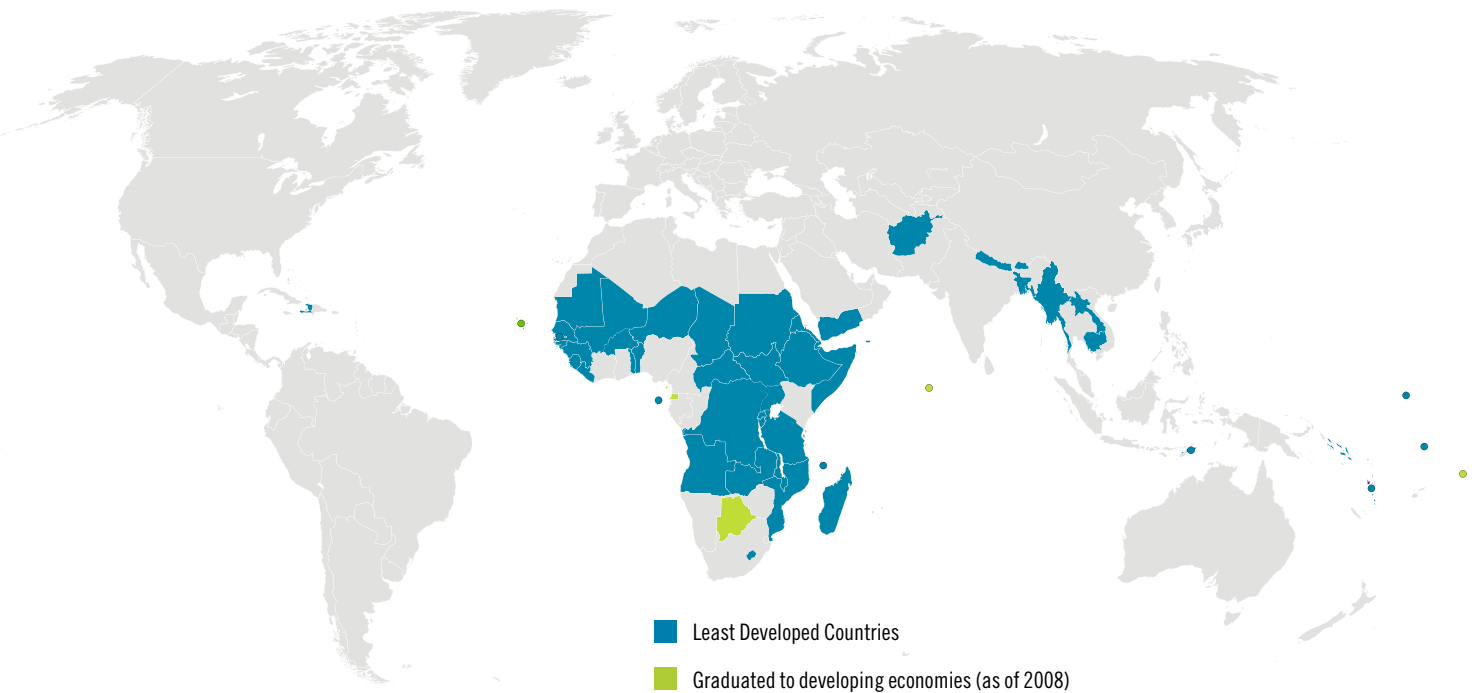
have low levels of reliable and affordable access to water, sanitation, hygiene and energy. Commonly, they have to cope with high levels of pollution (including water and soil pollution) and, depending on the geographical region, often experience direct and indirect effects of global warming (e.g. severe weather, flooding, draughts).

Against this background, **renewable energies** are particularly suitable for developing countries: especially in rural and remote areas, transmission and distribution of energy generated from fossil fuels, or large, centralised power plants can be difficult and expensive, leading to very low electrification rates in the majority of developing countries. Producing renew-

Dried digestate from anaerobic digestion process in rural Uganda

Developing countries tend to have some characteristics in common: amongst other criteria, they often





able energy locally (that is, in a decentralised way) can offer a viable alternative. Respectively, considering the conditions in developing countries described above, biogas technology can provide not only the energy needed for creating businesses and employment but also for cooking and lighting for (direct) domestic use. At the same time the **digestate**, as a second product besides biogas production, can be used for a variety of purposes, including organic fertilization towards increasing yields of agricultural production and crop health, and most importantly for ensuring environmentally sound and sustainable use of agricultural land.

For sub-Saharan countries in particular, **agricultural production** is limited by inadequate and/or erratic rainfall and poor soil fertility. In situations where the land available to a household for production of food and cash crops is only one hectare, the traditional method of restoring soil fertility by shifting cultivation becomes more and more difficult or is no longer possible. The rapidly increasing human population coupled with inadequate returns of plant nutrients to soils due to increasingly intensive cropping (utilisation pressure) and lack of knowledge about organic farming is likely to lead to an even more rapid **depletion of soil fertility** than already experienced in the recent past.

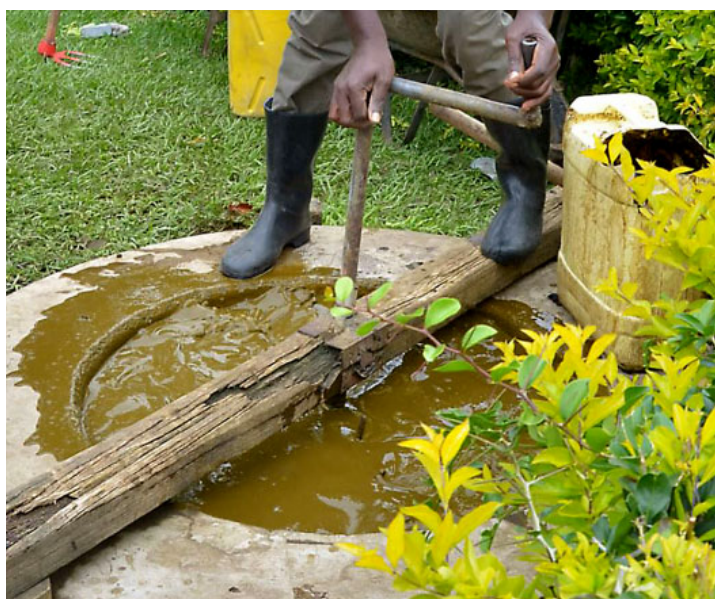
Organic matter is a key factor in soil fertility: a decline in the amount of organic matter can cause a reduction in the fertility of a soil, and also increase the risk of soil erosion. Deterioration of soil organic matter (SOM) varies according to agro-ecological zones, soil types and cropping patterns. Looking at the least developed countries as depicted above, it is more intense in East Africa, followed by coastal West Africa and Southern Africa and

least intensive in the Sahel and Central Africa. However, this is a phenomenon which can be observed not only on the African continent but also in Latin America and Asia.

Fertilization with organic matter such as compost or digestate from anaerobic digestion represents an alternative for sustainable agriculture. This especially applies to developing countries, because organic fertilizers are generally available at no or significantly lower cost in comparison to mineral fertilizers. Therefore, digestate from anaerobic digestion, regionally often called “bio-slurry”, can be considered as organic amendments or organic fertilizers, when properly handled and managed. However, the nutrient content of anaerobic digestate of all types depends primarily on the nature of the feedstock and the digestion process.

Sustainable farming aims at improving soil fertility by providing an ideal soil system for plant growth. It improves the physical, chemical and biological properties of the soil and thus builds up the soil's health. The problems inherent to tropical soils include soil acidity, excessive aluminium, deficient calcium, and low organic matter. Adding organic matter like digestate is sometimes the only means of making soils economically productive – and of doing so in an ecologically sound way. Therefore, the use of organic amendments is practically synonymous with soil productivity: increasing soil organic matter using digestate as fertilizer has the added benefit of improving soil quality and thereby enhancing the long-term sustainability of agriculture³.

³ Problems and Prospect of Organic Farming in Developing Countries, Bello. W. B., Ethiopian Journal of Environmental Studies and Management, Vol. 1 no.1 March 2008, <https://www.ajol.info/index.php/ejesm/article/viewFile/41568/8868>



Daily feeding of a domestic biogas plant: mixing cow dung and water



Distributing liquid digestate onto farm land by hand

9.1 Case study: Uganda

Renewable energy and biogas: status quo

As Uganda is richly endowed with Renewable Energy Resources (RES), the total estimated electrical power capacity potential is about 5,300MW. However, these resources remain largely unexploited. So far, only biomass (especially bagasse) and large hydro resources along the River Nile have been developed to some extent to provide electricity through a national grid. The other resources have remained largely untapped, including biogas. However, the renewable energy (RE) sector in Uganda has shown a permanent growth for the last 10 years and is expected to further increase.

Biogas in Uganda

The Government of Uganda supports the use of RE, including biogas. Both geography and climate in Uganda offer favourable conditions for the operation of biogas plants, especially the South-Western, Central and South-Eastern districts are the most attractive areas for large-scale commercialisation of biogas plants. These districts belong to the areas with the biggest fuel wood supply deficits, suggesting that biogas dissemination would have a large impact on forest resources and biodiversity conservation. In addition, the so-called cattle corridor stretches from Western to North-Eastern Uganda, where dairy farms and cattle breeding is common due to water resources and lush vegetation. As the Government is encouraging the use of RES, the current policy offers a conducive environment for adoption of technologies like biogas (e.g. import free taxation). In the last eight years, the country has seen an increase in the number of domestic biogas plants from about 600

(2009) to nearly 10,000 (2018). Sizes range from 3 to 30m³, while a few dozen institutional plants can be up to 300m³. Whereas the latter ones are mainly located at universities and schools and use human faeces as the main input source (with some cow dung and kitchen waste added to gain additional gas yield), domestic plants are fed with cow dung and water, producing biogas to operate cooking stoves. Typical feedstocks in Uganda include animal manure (cattle, goats, pigs and poultry), domestic organic waste (spoiled vegetables, food leftovers etc.) greens and plant waste (elephant grass, various leaves, banana peel) and human faeces.

Legal framework

The legal framework introduced by the Government aims at encouraging the use of biogas technology due to multiple benefits associated with the technology, including health, environmental as well as food security. For this, the Uganda National Bureau of Standards, advised by Uganda National Biogas Alliance (UNBA) in 2017, introduced national standards on biogas technologies (design and construction of different systems). However, the local market is difficult, especially for industrial and commercial biogas projects, because rather high initial investments limit the implementation of projects. The Ministry of Energy and Mineral Development (MEMD) is responsible for policy formulation, implementation and monitoring as well as for overall management of the country's energy sector. It implemented the Power Sector Reform and Privatisation Policy, which resulted in the liberalisation of Uganda's power sector.



Cabbage: High crop yields using digestate as fertilizer

Currently, there is no clear legal framework regarding the production and/or use of digestate in place in Uganda. However, the following regulations are in place:

- ▶ The National Environment (Standards for Discharge of Effluent into Water or on Land) Regulations, 1999 (S.I. No 5/1999);
- ▶ The National Environment (Waste Management) Regulations, 1999 (S.I. No 52/1999);
- ▶ The National Water Act, Cap. 152;
- ▶ The National Environmental Act, Cap 153. (1995).

With a tax rate of 10% on imported goods in addition to the Value Added Tax (VAT), this higher taxation applies to imported mineral fertilizer. This is one reason for the increasing use of organic fertilizer like digestate, compost, manure, etc.

Digestate production

The high costs for mineral fertilizer in Uganda have made digestate or bio-slurry applicable and attractive. In some areas, use of mineral fertilizer in the past proved harmful to soil. Agricultural policies greatly encouraged the use of digestate; the majority of farmers operating a biogas plant focus on digestate as a source of organic fertilizer rather than on biogas as an energy source. Digestate is also seen as a superior fertilizer for producing seedlings (e.g. coffee, tea), a high caloric feed for breeding poultry and feeding pigs and cattle – and even in fish farming (e.g. Nile perch, a high-grade and popular food fish) where it is used to fertilize fish ponds. The liquid phase of digestate is furthermore used as insecticide when sprayed on leaves.

Apart from promoting power generation, upgradation and the bottling of biogas, UNBA plans to support efforts to produce dried and packaged digestate as well as bio-cake for livestock feeding. These products will be sold to farming and fishing enterprises as well as to the public. The marketing of filtered bio-slurry has increased profitability and economics of the technology within the country. Furthermore, the sale of dried and packaged fertilizer from digestate will enhance cross-border trade between Rwanda and Kenya and may even encourage the use of digestate in Eastern Africa.

Supported by UNBA, private sector stakeholders are piloting the upgrading of digestate and promoting the use of this digestate together with the National Agricultural Organisation. It is expected that this market will increase in significance in the near future.

Facts & figures:

- ▶ Domestic biogas plants (3-30 m³ digester volume): approx. 10,000 plants
- ▶ Institutional biogas plants (30-300 m³ digester volume), e.g. schools, universities: approx. 100 plants
- ▶ Industrial/commercial biogas plants (20-100 kWh): approx. 10-20 plants



Further Information:

Uganda National Biogas Alliance www.unreeea.org/members/unba



Phase separation of digestate

9.2 Case study: India

Renewable energy and biogas: status quo

The currently installed renewable-based power generation capacity in India is 69 GW (2018). For bioenergy in particular, the Ministry of New and Renewable Energy has set a goal of 10 GW by 2022. The market for biogas has been largely scattered and primarily rural so far. Promotion of biogas technology is mainly undertaken by providing subsidies for biogas installations, i.e. small, community and large-scale plants under different programmes. Policy support is provided via tax holidays, provisions for the use of biogas in the transportation and power industry, market development through renewable purchasing obligations and renewable energy certificates as well as R&D programmes. However, effective implementation of such policies is still questionable.

Fertilizer use

India's agriculture contributes to around 13% of the country's gross domestic product (GDP). In 2016-17, the total recorded nutrient demand (N, P, K) from fertilizer was 25.95 million m³ tonnes. Presently, 20% of the urea requirement, almost the entire amount of potassium and 90% of phosphate are met through imports. The implementation of Indian Good Agricultural

Practices (INDGAP) is to ensure the optimum utilisation of pesticides, fertilizers, water, and eco-friendly agriculture; however, this presents challenges. Separation technologies range from drying to composting. Step-wise filtration along with reverse osmosis can be implemented for Zero Liquid Discharge, but that option calls for increased capital outlay. Under the City Compost Policy 2017, compost can be marketed, wherein a subsidy is provided. Fertilizer marketing companies are tagged by the Ministry of Agriculture (MoA) to facilitate selling the compost. Digestate produced from biogas plants is still not covered under this programme, thus its market is limited to the usage by interested local farmers near the producing plant.

Legal framework

The Fertilizer Control Order (FCO) is notified by the MoA to regulate the trade, price, quality and distribution of fertilizers. W.r.t organic fertilizers, only city compost from municipal solid waste (MSW), press mud and vermi-compost are covered under this order. Digestate from biogas plants is not specifically covered under the FCO. The Comprehensive Nutrient Management Plan (CNMP) has become an integral part of the regulatory landscape and environmental stewardship for animal

feeding operations of all sizes, and the same is being followed in India. The plan was developed to assist animal feeding operations in meeting nutrient levels and water quality goals and regulations. Furthermore, Indian water emission limits require the submission of an action plan or management programme that outlines nutrient land application rules as well as measures to meet permitting requirements related to any industrial effluent discharge.

Digestate production

In India, mineral fertilizers, in particular, are becoming increasingly expensive due to energy-intensive production and are responsible for a significant proportion of GHG emissions and water pollution from agriculture. Furthermore, with a depleting level of organic carbon in the soil, there is a great need to reduce the amount of mineral fertilizers and improve management of organic wastes.

A few examples and studies in India have cited the positive benefits of using digestate rather than manure on the crop yield of sugar cane, bananas, mango etc., although there is no comparative data on mineral fertilizer. Digestate must be integrated into the fertilization plan of farms in the same way as mineral fertilizers and applied at accurate rates, with equipment that ensures uniform applications throughout the whole fertilized area. Furthermore, the CNMP encourages the implementation of biogas plants, because use of digestate provides farmers with greater flexibility with regard to time and area of fertilizer application. A wide range of technologies are available to create novel digestate products - such as concentrated nutrient streams with the needed enrichment to produce standardised fertilizer products. However, operational experience of these technologies in India is currently limited and very often application of digestate in the vicinity is likely to remain the most economical option.

Vermi-composting of digested slurry from digester



Cattle shed



Arable land just before sowing and applied with digestate

Facts & figures:

- ▶ Small-scale (1-6m³/day): Approx. 4.6 million plants mainly used for household cooking
- ▶ Off-grid biogas plant (< 250KW elec. eq): Approx. 260 plants with cumulative capacity of 5.5MW
- ▶ Large-scale biogas plant (> 250KW elec. eq): Approx. 150 plants with cumulative capacity of 225MW elec. eq.



Further Information: Indian Biogas Association www.biogas-india.com





Pineapple plantation across Costa Rica's northern plains

9.3 Case study: Costa Rica

Renewable energy and biogas: status quo

For some years now, Costa Rica has been able to meet its electricity demand for most of the year entirely with renewable energy. This is possible thanks to an energy matrix which relies mostly on renewable sources: 75% hydro, 12.5% geothermal, 11% wind energy and 1.5% other sources like solar and biomass (2018). As if that was not impressive enough, Costa Rica has set a goal of becoming carbon neutral by 2021. However, the challenge does not lie in the energy sector, but in the transport and agricultural sector.

Pre-treated biogas feedstock from the pineapple plant



Currently, some 450 biogas plants are operated in Costa Rica, most of which are small domestic digesters. The Costa Rican Institute of Electricity (ICE) estimates the installed capacity of these digesters to be around 3.9MW, but only a handful of the digesters feed electricity into the grid, so the exact number is actually unknown. This installed capacity represents only 0.12% of the total national installed capacity. However, because Costa Rica is a known exporter of products like pineapple and bananas among other agricultural products, ICE estimates the potential at 113MW (31MW from pineapple residues).

Fertilizer use

Agriculture represents 4.6% of Costa Rica's gross domestic product (GDP) and is the second most important employment sector. Moreover, 46% of the country's exports are agricultural products like bananas and pineapple. On the other hand, the use of pesticides is quite intensive (9.6kg per hectare) with many harmful effects on groundwater and the neighbouring communities. Crops like pineapple and banana require lots of pesticides. Furthermore, climate change is forcing farmers to use more and more pesticides.

As in many countries, biogas plants in Costa Rica are more often than not closely related to an agricultural production system; however, only those plants located at dairies can actually use the digestate. Pig and poultry farms have to import the animal feed and, therefore, have little chance of using the digestate. Other biogas plants using sewage sludge have legal restrictions for using the effluent as fertilizer.

Generally, digestate is unknown as a fertilizing product, and this makes it difficult for the plant operators to com-



Biogas pilot plant at the pineapple plantation in Valle del Tarso

mercialise it. Currently, only one biogas plant upgrades the digestate by separating the solid and liquid fractions, whereby the solid fraction is used in an organic pineapple farm. The pilot biogas plant located in Valle del Tarso (north of the country) uses pineapple stubble as feedstock in a 10m³ digester, which generates approximately 250 litres of digestate per day. The digestate is being used as organic fertilizer in the pineapple plantation where the digester is located.

Legal framework

There is to date no specific legislation about digestate use in Costa Rica; however, there is an executive decree which regulates the discharge and reuse of effluents depending on their source. In this sense, for example, effluents from pig farming activities should not be reused on the land.

ICE and the Costa Rican Biogas Association are currently working on regulations for allowing the use of all effluents from biogas plants as fertilizer after a pasteurisation process.

Digestate production

According to ICE, some 766,000m³/a of digestate is currently being produced and only about 5% is being used as fertilizer. In order for this to change, potential consumers (farmers, construction markets, retailers,

etc.) should be informed about the product and its advantages and uses. Some work also needs to be done by the operators of the biogas plants, who often fail to recognise the potential market opportunities when upgrading the digestate (separating, pelletising, packing, etc.), which improve its marketing possibilities.

Additional information

Since 2015, the Costa Rican Biogas Association has been representing the sector and generating valuable information regarding the technology. Likewise, the Biogas program of ICE promotes and supports biogas projects in the industry in order to generate energy for self-consumption. Together, both entities are working to develop national biogas technology standards.

Facts & figures:

- ▶ Number of biogas plants: 450 (mostly small to medium-sized)
- ▶ Total installed capacity: 3.9MW
- ▶ Estimated current amount of produced digestate per year: 766,000m³



Further Information: Programa Biogás, Instituto Costarricense de Electricidad (www.grupoice.com) y Asociación Costarricense de Biogás www.asobiogas.org

Pineapple plantation



10 Safety first!

Biogas and digestate upgrading plants are complex plants in terms of process technology that can pose various hazards to people and the environment. For the plant to operate safely, it is absolutely necessary to observe certain safety recommendations and put them into practice in the plants!

To ensure that the operation of biogas and digestate upgrading plants does not pose a risk to health and the environment, manufacturers, planners, and operators should work closely together from the outset. Decades of experience have shown that, starting from the planning phase, the plant must be designed in such a way that as few hazards as possible can occur during operation. This includes the use of safe and high-quality components that are easy to handle and maintain by the future operator. Manufacturers of digestate upgrading plants should also provide the legally required documentation and instructions for safe operation and maintenance.

Environmental hazards particularly include emissions to air, for example from the release of methane and the release of digestate, as well as the associated pol-

lution of water bodies. In digestate upgrading plants, increased ammonia emissions can also result from drying.

The energy source methane (CH_4) can pose health hazards. When mixed with air (4.4 - 16.5% CH_4), a hazardous explosive atmosphere may form. This can also be the case with drying digestate and dust formation. To avoid the risk of explosion or fire, zones in which a hazardous explosive atmosphere may occur should be equipped with appropriate protective and warning devices. This should be documented in an explosion protection document and implemented in the plant. An additional fire risk can arise in drying plants due to the self-heating of still active digestate during storage. If a certain amount of residual moisture is still present, an enormous amount of heat can be released by the activity of the bacteria, which can lead to spontaneous combustion and, in combination with dust generation, even to the risk of explosion.

However, the main hazards are not biogas-specific. There are, for example, mechanical hazards such as moving parts in plants. There is also a certain risk through biological and chemical substances, such as bacteria, moulds, or additives and auxiliary substances. Biogas itself and its components are also dangerous; they can be toxic and suffocating.

In order to be able to assess the listed hazards and the necessary protective measures, it is absolutely necessary to prepare a risk assessment for all activities in the plant. The operator should document which hazards can occur, how high the probability of occurrence is, and how severe the resulting consequences for the environment and health can be. Appropriate protective measures must be taken on this basis. It is also essential for safe plant operation that the operating personnel is trained in accordance with the risk assessment and regularly instructed on potential hazards as well as regular maintenance in accordance with the manufacturer's instructions. Further information on safety can be found in the brochure "Safety First!" at www.biogas-safety.com.



Reference plants



Agro Energie Hohenlohe



Biogas plant of Agro Energie Hohenlohe

Presented technology: Complete treatment, nutrient recovery

Manufacturer of the upgrading unit:
Geltz Umwelttechnologie

Commissioning year: 2001

Installed capacity:
1,250 kW_{el}

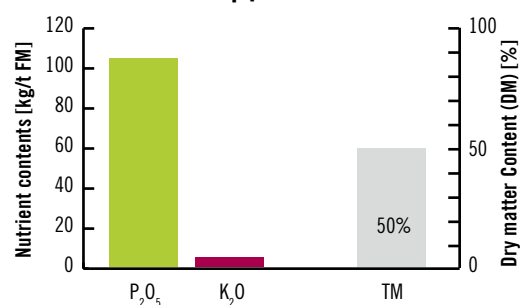
Amount of produced digestate:
25,000 t/a



The biogas plant of Agro-Energie Hohenlohe substitutes the use of renewable raw materials as far as possible. Manure, grass cuttings, leftover foods and other residual materials are used as substrates. Agro-Energie Hohenlohe runs a demonstration plant for the complete treatment of digestates with a throughput of 1 cubic metre of digestate per hour.

The plant recovers phosphate salts by precipitation, nitrogen solution by stripping, low-nutrition soil conditioner by filtration and cleaned residual water separately. This process eliminates the storage difficulty of digestate. A bigger plant with a throughput of 10 cubic metres of digestate will be built by the end of 2018. The throughput of this plant will be enough to treat the whole digestate of the biogas plant. The recovered raw materials will be sold to wholesalers, rural cooperatives, the chemical industry and local customers.

Phosphate salt



Operator

Agro Energie Hohenlohe

Bachstraße 48

74635 Kupferzell

Germany

Contact person: Thomas Karle

Telephone: +49 7944 950102

Mail: info@nadu-naturduenger.de

Website: www.nadu-naturduenger.de

Generated products: Granules, dischargeable water, ammonium sulphate solution, ammonium phosphate

Use of the digestate: Spreading as fertilizer, treatment in a public sewage plant, drag horse spreader

Marketing the digestate: Retail sale (e.g. home improvement market, garden centre)

Maier GbR



Digestate evaporator "Vapogant" on the Heslerhof with upstream separation



The digestate evaporation plant "Vapogant" went into operation in Dec. 2014 and has a capacity of over 95%.

Construction: Mechanical separation precedes the digestate evaporation where the digestate passes through a fine-meshed screen (e.g. 0.5 mm) to be separated in a liquid and a solid phase. The liquid phase with about 5–6% DM is fed to the digestate evaporation process. In the plant, the liquid phase is heated and placed under vacuum. In this case, part of the liquid phase evaporates; the digestate is thus thickened and concentrated to up to 15% DM. The digestate evaporator consists of two evaporator stages and therefore has an evaporation capacity of 2.5 liters per kW_{therm} . Inside the vapour cleaner, the gas phase that is produced through heat and vacuum is stripped of ammonia by adding sulphuric acid. In this process, ammonia is converted into ammonium sulphate and concentrated. The vapour produced in this process, which has been stripped of ammonia, is condensed to water (distillate) in heat exchangers. The distillate is used in the wet cooling tower as a cooling medium in the heat exchangers of the condenser. The plant is sealed hermetically, resulting in a low-emission process.

Operator

Maier GbR

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88316 Isny

Germany

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Presented technology:

Vapogant digestate evaporator

Manufacturer of the upgrading unit:

Biogastechnik Süd GmbH

Manufacturer of the biogas plant:

self-made

Commissioning year: 1999

Installed capacity:

865 (flex) / 400 kW_{el}

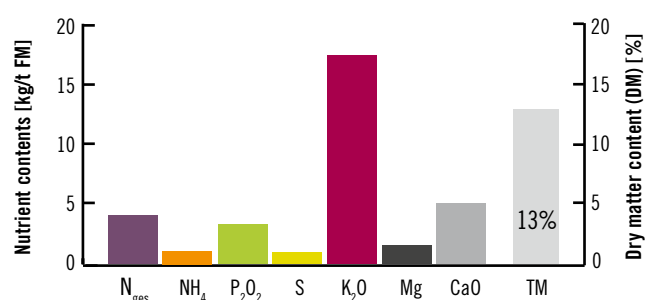
Amount of produced digestate:

8,500 t/a



At the end of the process, the concentrate (the thickened liquid phase of the digestate) exits the process under vacuum. This digestate is now concentrated and contains all nutrients also found in untreated, non-dried digestate with the exception of ammonia. This highly volatile substance is concentrated in the form of ammonium sulphate solution (ASS). Subsequently, the ASS is stored in a separate tank and can either be used selectively as a mineral fertilizer or sold.

Thickened digestate (liquid phase without ASS)



Generated products: Liquid digestate, solid digestate, dischargeable water, concentrated nutrient solution, ammonium sulphate solution

Use of the digestate: Spreading as fertilizer, drag horse spreader, injection technique, drag shoe spreader, spreading solid digestate

Conditioning the digestate: Production of ASS fertilizer

BN Nordhümmlinger Biogas GmbH & Co. KG



BN Nordhümmlinger Biogas GmbH & Co. KG places great importance on the efficient spreading of digestate – this is done with a dribble bar system, a Strip Till unit and direct incorporation



BN Nordhümmling GmbH is jointly operated by four partners in Börger. It supplies two satellite cogeneration units that provide heating for a workshop for the disabled, a school, a gym, a kindergarten and a swimming pool in Börger. As a result, the biogas plant enjoys a high level of acceptance in the community. The feeding of the biogas plants, as well as the end products, are processed without export and within a radius of around 10 kilometers. The plant operators place particular importance on the efficient use of digestate. They use, among other things, the Vogelsang SwingUp dribble bar system with a working width of 15 metres, the Vogelsang XTill as a Strip Till unit and a short disk harrow from Pöttinger with the SynCult retrofitting set from Vogelsang. The various technologies enable optimum liquid manure spreading and incorporation for different requirements and plants with the SwingUp dribble bar system used mainly for grain. The end hoses divide the crops and deposit the liquid manure directly under the plant, close to the soil and with low emissions. The nutrients are thus placed exactly where the plant needs them.

Operator

BN Nordhümmlinger Biogas GmbH & Co. KG

Tannenweg 1

26904 Börger

Germany

Contact person: Wilfried Sievers

Telephone: +49 5953 926841

Fax: +49 5953 925126

Email: wilfriedsievers@gmx.de

Presented technology:

Dribble bar system SwingUp

Manufacturer of the upgrading unit:

Vogelsang GmbH & Co. KG

Manufacturer of the biogas plant:

Biogas Weser Ems

Commissioning year: 2005

Installed capacity: 1,950 kW_{el}

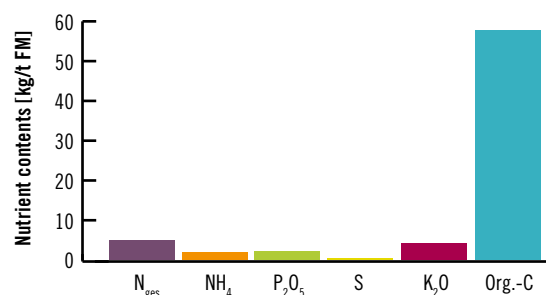
Amount of produced digestate:

20,000 t/a



The XTill Strip Till unit allows several work processes in one: plowing, cultivating, seed bed conditioning and liquid manure incorporation are carried out in one step. The operators use strip tillage before sowing maize. For the direct incorporation of liquid manure into the grain and maize crop, BN Nordhümmling uses a short disk harrow in combination with the SynCult from Vogelsang. The retrofitting set allows efficient use of nutrients.

Digestate to be applied



Generated products: Liquid digestate, dried digestate

Use of the digestate: Drag horse spreader, drag shoe spreader, stripp-Till, soil incorporation (e.g. cultivator)

Conditioning the digestate: Micronutrients

Regeb Bersenbrück



Biogas plant Bersenbrück, vacuum evaporator from Arnold



At the biogas plant in Bersenbrück, the digestate is mechanically separated from the repository and separated into a liquid and solid phase. The separated liquid digestate filtrate is heated in the Arnold evaporator by the waste heat from the CHP unit in heat exchangers and then evaporated under vacuum. The digestate is thus thickened and concentrated. The multi-stage arrangement multiplies the evaporation capacity at a constant heating capacity and thus guarantees the recycling of the entire quantity of digestate produced. The system installed in Bersenbrück requires just $0.28 \text{ kW}_{\text{therm}}$ for 1 litre of water evaporation. In order to prevent ammonia from evaporating, the pH value of the digestate is lowered by means of sulphuric acid before evaporation. All the nutrients contained in the starting product can be found in the thickened concentrate. Thus a maximum separation of liquid and nutrients is achieved without unwanted by-products!

Presented technology: Vacuum evaporation

Manufacturer of the upgrading unit:

Arnold & Partner AG

Manufacturer of the biogas plant:

BioConstruct

Commissioning year: 2011

Installed capacity:

1,300 kW_{el}

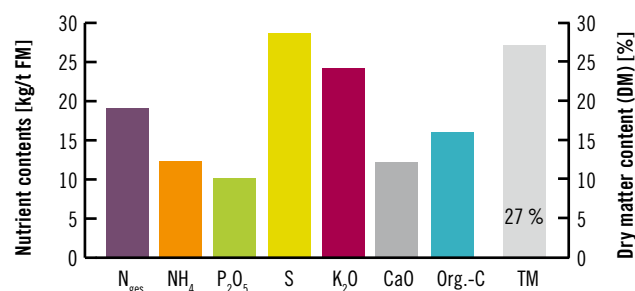
Amount of produced digestate:

30,000 t/a



The condensate is discharged into the receiving water. Transport and disposal costs are greatly reduced by reducing the volume of liquid digestate by around 70%.

Concentrated digestate after vacuum evaporation



Generated products: Liquid digestate, solid digestate, dischargeable water

Use of the digestate: Spreading as fertilizer, drag hose spreader, injection technique, soil incorporation e.g. cultivator)

Operator

Regeb Energieerzeugung und
-Verteilung Bersenbrück

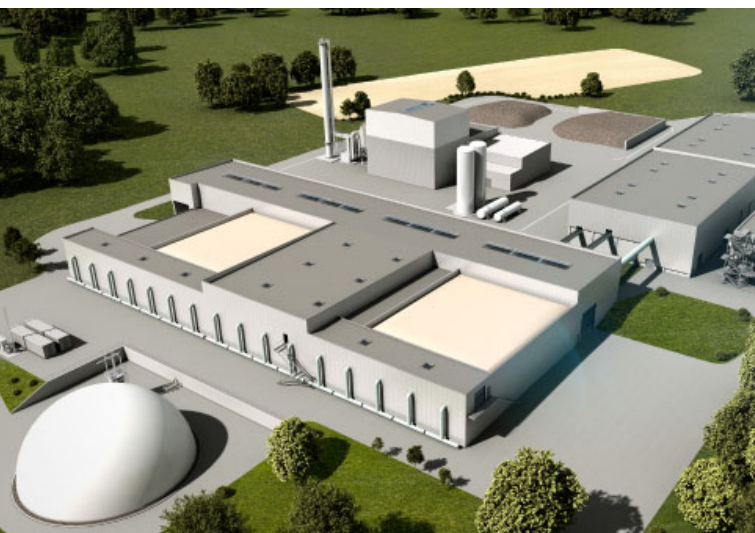
Hermann-Kemper-Str. 5
49593 Bersenbrück
Germany

Contact person: Christian Rauf

Telephon: +49 5439 609626

Mail: g.erpenbeck@regeb.de

AVR Sinsheim



Biogas plant Sinsheim – Liquid digestate “free” biowaste fermentation plant – Copyright AVR Bioterra



Biogas plant Sinsheim:

Input: min. 60,000 t/a biowaste and green waste – with upgradable biowaste utilisation

Biowaste treatment: Eggersmann biowaste Treatment

Fermentation process: Thöni plug-flow fermenter in partial flow 2 x 2,250 m³

Digestate conditioning: Eggersmann digestate conditioner

Composting: Eggersmann composting tunnel

Biogas utilisation: Friedrich Vorwerk biogas treatment/ membrane process

The biogas plant in Sinsheim will be characterised by a highly efficient heat utilisation concept of heat from the adjacent CHP. The heat is used on, the one hand, for the thermophilic management of plug-flow fermenters; on the other hand, the heat is fed to a digestate conditioner and the composting tunnels. They ensure

Presented technology:

Plug-flow fermenter, digestate conditioner, composting tunnel

Manufacturer of the upgrading unit:

Thöni Industriebetriebe GmbH,
Eggersmann Gruppe GmbH & Co. KG

Commissioning year:

2019

Installed capacity

Up to 1,100 Nm³/h

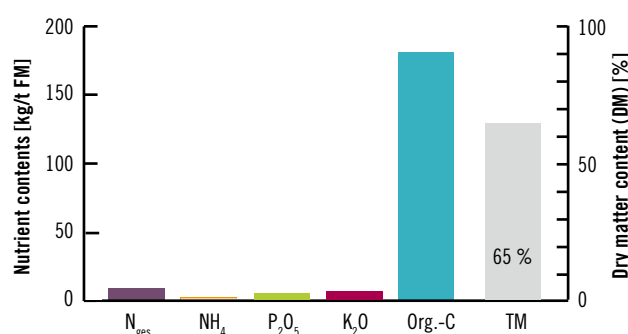
Amount of produced digestate

15,000 t/a



that a liquid digestate is avoided by discharging water and adjusting the necessary moisture content of the solid digestate. This ensures efficient composting.

Digestate conditioner



Operator

AVR BioTerra GmbH & Co. KG

Dietmar-Hopp-Strasse 8

74889 Sinsheim

Germany

Mail: info@avr-bioterra.de

Website: www.avr-bioterra.de

Generated products: Compost, ammonium sulphate solution

Use of the digestate: Spreading as fertilizer

Marketing the digestate: Horticulture

Total digestate treatment plant in Inwil



The Total digestate treatment plant has been running successfully since 2008

Presented technology:

Total digestate treatment plant

Manufacturer of the upgrading unit:

A3 Water Solutions GmbH

Manufacturer of the biogas plant:

CTU Clean Technology

Universe AG

Commissioning year:

2007

Installad capacity: 1,350 Nm³/h

Amount of produced digestate: 45,500 t/a



Planning, construction, and delivery of a system for the treatment of digestate from biogas plants. The digestate is highly loaded with CSB, nitrogen and phosphorus. After a solids-liquids separation, the fluid phase is treated with ultra-filtration and multi-stage reverse osmosis. In addition to dischargeable water, the final product consists of concentrated nitrogen, phosphorus and potassium.

For over ten years, A3 Water Solutions convinces with innovative technologies for digestate treatment using the MPS method (Multi-Phase-Separation).

The reference plant Inwil in Switzerland has been running continuously since 2008. The digestate is treated in the cleaning process in a way that the run-off water can directly be discharged in the sewage system. If required, an extension can be added to achieve direct discharge quality for discharging into the receiving water.

The different stages of the treatment process separate nitrogen and phosphorus into individual fractions. They can be used separately as plant fertilizer – depending on the regional conditions. In the course of a 4-year-project funded by the DBU (Deutsche Bundesstiftung Umwelt), the performance of the entire system was increased further this year.

The optimised operating method of the ultrafiltration method at high operating temperatures has been implemented in France for the first time.

In this case, the application of the Hot Ultrafiltration method reduces the demand for energy for the treatment by up to 50 percent. With this, the waste heat from the CHPs is used which is partially eligible for the KWK bonus.

Operator

Total-Gärproduktaufbereitungsanlage

Inwil

Im Feld

6034 Inwil

Schweiz

Contact person: Ulrich Brüb

Telephone: +49 2574 8875 820-0

Fax: +49 2574 8875 820-1

Mail: info@a3-gmbh.com

Website: www.a3-gmbh.com

Generated products: Liquid digestate, solid digestate, dischargeable water, concentrated nutrient solution

Use of the digestate: Spreading as fertilizer

Marketing the digestate: Horticulture, landscaping, gardening

Biogas Plant Hashimoto



Press screw separator on the biogas plant with a view on the sieve



Some Japanese farmers have begun considering biogas technology to allow them to turn their properties into power plants, giving them a way to transform animal and other waste into profit.

The push towards this type of green energy production has been promoted through the government's feed-in-tariff, or FIT system introduced in 2012 to encourage the use of renewables following the March 2011 Fukushima nuclear meltdown.

Unlike Germany and some other countries, the history of biogas in Japan is short and the market still has the potential to grow.

Despite biogas being more expensive than other forms of renewable energy, the farmers choose it because it provides them with a way to dispose of waste while generating power during 24/7 operation.

The biogas plant uses wastes from food factories such as sweets, ice cream, food wastes from restaurants and animal excrements such as pig slurry and horse manure.

Operator

Biogas Plant Hashimoto

Fukaya-shi

Saitama-ken 366-0041

Japan

Contact person: Mr. Shinozaki

Mail: sekine@utopia.ocn.ne.jp

Presented technology:

Separation

Manufacturer of the upgrading unit:

Erich Stallkamp ESTA GmbH

Manufacturer of the biogas plant:

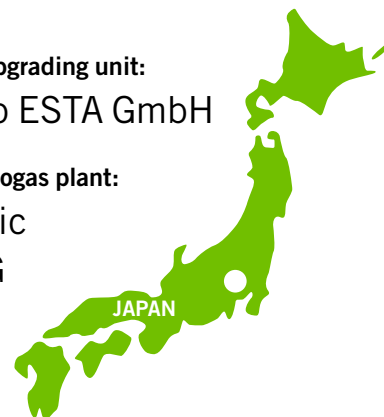
TEWE Electronic GmbH & Co.KG

Commissioning year:

2017

Installed capacity: 370 kW

Amount of produced digestate: app. 12,500 tonnes



After digestion, the digestate is treated with separation during the preliminary stage of the waste water treatment plant, which was especially built for this biogas plant. The reduction of dry matter ensures an efficient cleaning of the liquid phase. Afterwards, the cleaned water is passed into the public waste water system.

The separator is fed with the digestate of the biogas plant. At the inlet, the digestate has a dry matter of 7%. During the separation process, the press screw presses the digestate through a sieve. Thus, the solid material is conveyed to the outlet, building a plot. It then has a dry matter of 28%. The liquid phase has only 3.5% dry matter and is conveyed to the specific waste water treatment plant.

The advantages of separation are obvious; the separation of solid and liquid is the first step of the waste water treatment plant. Some of the liquid phase can also be used to improve the viscosity in the digester tank. Moreover, the transportability of excessive solids is more efficient.

Generated products: Liquid digestate, solid digestate

Use of the digestate: Treatment in a private sewage plant built for the biogas plant

Tully AD Plant



ByoFlex 20 Stripper Ballymena



The Tully Centralised Anaerobic Digestion Plant being led by Stream BioEnergy Ltd. and built by Xergi and local firm BSG Ltd uses the innovative nitrogen stripping technology of Byosis to allow the plant to use up to 100% poultry litter and is thereby one of the first anaerobic digestion plants in the world able to do so.

The Tully AD plant generates 3MW of renewable electricity from 40,000 tonnes per year of locally-sourced poultry manure by combining the anaerobic digestion technology of Xergi with the nitrogen-stripping technology of Byosis. The plant produces enough sustainable energy to power the equivalent of 4,000 homes, diversifying Northern Ireland's fuel mix and reducing the country's reliance on fossil fuels – as well as the emission of greenhouse gases into the atmosphere.

With the unique ByoFlex stripper, a substantial part of the nitrogen is continuously removed to prevent the inhibition of the bacteria in

Presented technology:

ByoFlex Nitrogen Stripper

Manufacturer of the upgrading unit:

Byosis Group BV

Manufacturer of the biogas plant:

Xergi A/S

Commissioning year:

2017

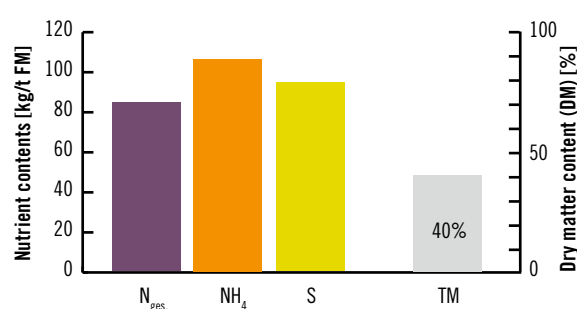
Installed capacity: 3,000 kW_{el}

Amount of produced digestate: 40,000 t/a



the anaerobic digesters. The system is capable of processing 20 m³/hr of digestate. The removed nitrogen is transformed into ammonium sulphate, a nitrogen rich fertilizer with 40% DM content.

Ammonium sulphate



Operator

Tully AD Plant

Tully Quarry, 116 Moorfields Road

BT42 3HJ / Ballymena

Northern Ireland

Contact person: Bjorn Zwijnenberg

Phone: +31 85 13 02 382

Mail: info@byosis.com

Website: www.byosis.com

Generated products: Ammonium sulphate solution, liquid digestate

Use of the digestate: Spreading as fertilizer, spreading solid digestate

Marketing the digestate: Horticulture, B-to-B

Company directory

SYMBOL DESCRIPTION:

Direct application



Laboratory / Measuring



Separation



Composting



Drying / Atmospheric evaporation



Pelletising



Vacuum evaporation



Membrane filtration



Precipitation





Stripping



Waste water treatment



Matrix overview of the company directory

Company												Page
Provider of digestate upgrading technology												
A3 Water Solutions GmbH	X		X					X	X	X	X	48
AgroEnergien GmbH & Co. KG	X				X			X	X		X	48
Arnold & Partner AG							X			X	X	49
Biogastechnik Süd GmbH	X		X				X					49
Börger GmbH	X		X								X	50
Byosis Group BV		X	X		X				X	X	X	50
Erich Stallkamp ESTA GmbH	X		X									51
Geltz Umwelttechnologie GmbH			X					X	X	X		52
LMEngineering GmbH						X						52
Thöni Industriebetriebe GmbH	X		X	X								53
Eggersmann Gruppe GmbH & Co. KG				X	X							53
MKR Metzger GmbH					X		X		X			54
Application technologies												
HOLMER-Maschinenbau GmbH	X											54
Vogelsang GmbH & Co. KG	X											55
Process auxiliaries												
Franz Eisele u. Söhne GmbH & Co. KG	X		X									56
Hermann Sewerin GmbH		X										56
Project developer												
EnergiEffekte GmbH			X	X	X	X					X	57



A3 Water Solutions GmbH is an international operating plant construction and service company, which is your contact for any questions regarding water. As plant construction company with consulting, planning and development expertise in the areas of water production and wastewater treatment, we support customers from the economic, industrial and administrative sectors to overcome environmental challenges.



Total digestate treatment plant in Inwil, successfully operating since 2008

Our services include process design, plant piloting and manufacturing, operation & maintenance support and after-sales service. By combining our innovative process concepts and the experience of an international plant manufacturer, the A3 Water Solutions GmbH offers highly innovative and cost effective solutions.



- ▶ Feedstock preparation
- ▶ Manure and digestate treatment
- ▶ Treatment of surface water

Year of foundation **2000**
Number of employees **11**

A3 Water Solutions GmbH

Boschstr. 2
48369 Saerbeck · Germany
Contact person: Ulrich Brüb
Phone: +49 2574 8875 820-0
Fax: +49 2574 8875 820-1
Mail: info@a3-gmbh.com
Website: www.a3-gmbh.com



AgroEnergien, your innovative 24/7 partner from the idea to the project since 2001.

In the field of digestate treatment, we are highly proud of our Mississippi® system.

Mississippi digestate drying means pumpable digestate IN & OUT, very low power consumption, minimal maintenance, dust free ammonia scrubbing and a fast return on investment. High evaporation rates minimise storage, transportation and application costs.



Mississippi digestate dryer and ammonia scrubber

Our Mississippi digestate dryer has been installed over 150 times, both nationally and internationally. References can be provided, or have a look at:
www.mississippi-digestate-dryer.de



- ▶ Digestate drying
- ▶ Manure treatment
- ▶ Waste water treatment
- ▶ Nitrogen removal
- ▶ Ammonia stripping

Year of foundation **2001**
Number of employees **3**

AgroEnergien GmbH & Co.KG

Brunner Str. 18
26316 Varel · Germany
Contact person: Burkhard Meiners
Phone: +49 4453-98580-0
Fax: +49 4453-98580-2
Mail: info@agroenergien.de
Website: www.agroenergien.de



- ▶ Digestate marketing
- ▶ Vacuum evaporation
- ▶ Agitator technology
- ▶ Stripping

Year of foundation **2004**
Number of employees **12**

Arnold & Partner AG

Industrie Nord 12
6105 Schachen · Switzerland
Contact person:
Dipl. Mech. Eng. ETH André Wicki
Phone: +41 41 499 60 00
Mail: info@arnoldbiogastechnik.ch
Website: www.arnoldbiogastechnik.ch



Arnold vacuum evaporator unit



Arnold & Partner AG, which emerged from Arnold Umwelttechnik AG, was founded in 2004. Over 35 years of experience in the field of digestate, manure and waste water makes us a reliable partner.

Within a short time, Arnold & Partner AG has developed into a medium size contractor, which offers turn-key solutions for nutrient recovery from waste water, digestate and slurries. The Arnold vacuum evaporator reduces the volume of waste water, as liquid manure and digestate by up to 90% very efficiently by means

of low-temperature energy. The waste water is separated into clear water and concentrate with all of its nutrients. The concentrate is a valuable biological fertilizer and even replaces expensive mineral fertilizer.

Transport costs, storage volumes and associated costs are highly reduced by means of an Arnold vacuum evaporator. By compacting the nutrient-rich dry matter into pellets, the final product is a valuable organic farm fertilizer – the cycle is closed.



- ▶ Agitator technology
- ▶ Service and maintenance
- ▶ Feedstock preparation
- ▶ Safety technology
- ▶ Digestate refining

Year of foundation **2002**
Number of employees **50**

Biogastechnik Süd GmbH

Am Schäferhof 2
88316 Isny i. Allgäu · Germany
Contact person: Gregor Maier
Phone: +49 7562 97085-40
Fax: +49 7562 97085-50
Mail: info@biogastechnik-sued.de
Website: www.biogastechnik-sued.de



Clemens Maier (left) and Gregor Maier (right)



Biogastechnik Süd has been producing a wide range of components for biogas plants since 2002. It began in 1999 when the two managing directors, Clemens and Gregor Maier, built their own biogas plant on the farm they were running together. Dissatisfied with the agitator performance, they upgraded the system with their own paddle agitator Varibull. Word got around of the high efficiency of the new paddle agitator and soon Gregor and Clemens Maier were selling their Varibull paddle agitator throughout Germany. Gregor and Clemens Maier are continuously working on improving the technology for

biogas plants. In rapid succession, they invented, developed and built the Easyfeeder feeding system, the Sepogant press screw separator, the Varipeller submersible agitator and a mini biogas plant optimised for slurry fermentation.

The brothers want to help farmers save on costs for the storage of digestate and for transporting biogas products to the field with what is probably the largest plant developed at Heslerhof, the Vapogant digestate evaporator. Furthermore, the Vapogant can separate ammonium nitrogen from the digestate cycle.



Börger designs, produces and sells pumps, macerators and stainless steel tanks as well as feeding, separation and agitator technology. The high level of quality, the high efficiency and the ease of maintenance are the characteristics of Börger products.

The new liquid feeding technology Powerfeed twin is equipped with an integrated macerating function and defibres the biomass while it is fed into the system. This results in a higher gas yield in the fermenter without an additional macerator. The Börger Bioselect stands for efficient separation technology.



Börger's extensive product range

Liquid and solid parts are separated using a purely mechanical process. The content of dry solids is infinitely variable between 18% and 38% with all four sizes of the Bioselect, featuring maximum capacities of 20 and 150 m³/h. Penetration-proof separation technology can be installed as a stationary or mobile unit.

On request, Börger supplies a ready-to-connect complete unit including control unit and rotary lobe pump.



- ▶ Pump technology
- ▶ Separation technology
- ▶ Liquid feeding technology
- ▶ Agitator technology
- ▶ Feedstock preparation

Year of foundation **1975**

Number of employees **330** (worldwide)

Börger GmbH

Benningweg 24

46325 Borken-Weseke · Germany

Contact person: Markus Einck-Roßkamp

Phone: +49 2862 9103-30

Fax: +49 2862 9103-47

Mail: info@boerger.de

Website: www.boerger.de



Byosis supports clients with new innovative solutions and has proprietary technologies such as ammonium stripping, gas scrubbing and pasteurisation. Byosis solutions are easy to add to an AD plant and always aim to improve the use of biomass and/or reduce the spreading out of costs of digestate.



Nitrogen stripping, Bad Bentheim

With the solutions, the business case will be more robust and revenue will be better. Byosis also provides technology developed by third parties (such as decanters, separators and dryers). The Byosis engineers are perfectly capable of interconnecting systems, whether they be greenfield projects or rebuilding projects.



- ▶ Low feedstock costs
- ▶ Nitrogen stripping
- ▶ Phosphate reduction
- ▶ Saving storage volume

Year of foundation **2007**

Byosis Group BV

Drosteweg 8

8101 Raalte · The Netherlands

Contact person: Bjorn Zwijnenberg

Phone: +31 85 1302 382

Mail: info@byosis.com

Website: www.byosis.com



Separator with 2,2 kW; Throughput: 7-10 m³



Separator with 4 kW separates digestate



- ▶ Separation technology
- ▶ Full digester construction
- ▶ Pumping technology
- ▶ Agitator technology

Year of foundation **1973**
Number of employees **200**

Erich Stallkamp ESTA GmbH
In der Bahler Heide 4
49413 Dinklage - Germany
Contact person: Benjamin Budde
Phone: +49 4443 9666-0
Fax: +49 4443 9666-60
Mail: info@stallkamp.de
Website: www.stallkamp.de

Stainless steel or nothing

As a specialist in construction and assembling of stainless steel products such as digesters, pumps, agitators and separators, Stallkamp is a competent partner for agriculture, biogas and wastewater industry. Its wide portfolio is successfully applied all over the world.

Separation technology

The press screw separators from Stallkamp divide manure or other waste water into a solid and a liquid phase. Therefore, the medium is supported through the stainless steel sieve where an armoured press screw permanently cleans the sieve from the inside. The separated liquid phase flows out of the sieve. The solids are supported to the throw-off. The counter pressure of the hydraulic ball head adjusts the desired content of dry matter.

Separator for agricultural application

Every medium is different and the application of the separator often not comparable. However, Stallkamp separators already revealed that they operate reliably in various areas. Many separa-

Stallkamp



tors work with cow, bull, and pig manure. The advantages are obvious: reduction of storage capacity, improved mixing conditions, improved spreading of slurry and production of bedding material. Besides, Stallkamp press screw separators are running on many biogas plants.

Industrial application

Some examples show that the separators are applied in different industries:

- paper industry: pressing out paper processed water
- food processing industry: pressing out potato sludge
- breweries: pressing out pulp
- plastic industry: pressing out plastic residues
- wastewater treatment plants: pressing out sewage sludge
- animal truck washing plant: pressing out dung residues

Technical details

The smallest stainless steel separator with a 2,2 kW engine and a sieve length of 400 mm reaches a throughput up to 12 m³/h. The separator with 4 kW or 5,5 kW engine and a sieve length up to 550 mm has a throughput up to 25 m³/h. The biggest separator is available with engines ranging from 3 kW, 4 kW and 5,5 kW and a sieve length of 600 mm or 750 mm. This separator is built with a cast iron housing and reaches higher dry matter contents.

Immediately usable

All basic machines can be extended to a mobile unit including two pumps (rotary lobe pumps or eccentric screw pumps) for in- and outflow. Thus, the machines are immediately usable. Furthermore hoppers and chassis are part of the accessory.



Pilot facility, throughput 1 cubic metre of digestate per hour

Geltz has been working on the recovery of plant nutrients from agricultural residues as a waste water and special plant engineering firm with a strong commitment to research and development for over 8 years. Using the experience gained, Geltz developed a complete treatment plant for targeted nutrient recovery and treatment, which purifies digestate from its raw state all the way to clean water.

Biomass, phosphorous and nitrogen are almost fully recovered. The biomass is used as a low-

nutrition soil conditioner. Phosphates are recovered in an apatite-like quality and nitrogen as a high-quality ammonium sulphate solution. The residual water is spread on farmlands or directly discharged after an additional step.

Geltz currently operates a pilot facility with a throughput of 1 cubic metre of digestate per hour. Geltz is building a facility with a throughput of 10 cubic metres of digestate per hour, called "NuTriSep", which will be completed by the end of 2018.



- ▶ Nitrogen recovery
- ▶ Full treatment of digestate
- ▶ Residual water treatment
- ▶ Phosphate recovery
- ▶ Digestate disposal

Year of foundation **1999**
Number of employees **25**

Geltz Umwelttechnologie GmbH

Kerschensteinerstr. 6
75417 Mühlacker - Germany
Contact person: Ulrich Geltz
Phone: +49 7041 829910-0
Fax: +49 1041 829910-27
Mail: info@geltz.com
Website: www.geltz.de



Spreadable digestates as fertilizer: powder and granulate

Regulations on manuring contain extensive restrictions for spreading and are, therefore, a strain on farmers. Digestates and liquid manure offer a large potential of nutrients, but to spread them as liquid bears disadvantages that can't be neglected. The company LMEngineering GmbH is offering a solution for this severe problem: ammonium(-di-)carbonate fibres (ACF). LMEngineering has developed a simple, sturdy and cost-efficient procedure to make digestates and liquid manure usable. Water does evaporate by using small amounts of carbonate chalk and natural fibres. The fibre stores nutrients and emits them to the plants.

Further advantages are:

- low emission during production process, storage and after manuring
- high plant availability
- spreadable
- fertilizer value is easy to adjust by simply adding different amounts of the fertilizer – as required
- good air void volume and water holding capacity
- multicomponent fertilizer, optimises fertilising and pH value of the soil



- ▶ Service and maintenance
- ▶ Feedstock preparation
- ▶ Production of fertilizers
- ▶ Bioextrusion

Year of foundation **2007**
Number of employees **5**

LMEngineering GmbH

Jocketa – Bahnhofstraße 34
08543 Pöhl - Germany
Contact person: Markus Lehmann
Phone: +49 37439 744-39
Fax: +49 37439 744-9039
Mail: info@lmengineering.de
Website: www.lmengineering.de



- ▶ Digestion technology
- ▶ Agitator technology
- ▶ Separation technology
- ▶ Service and maintenance

Year of foundation **1964**
Number of employees **600**

Thöni Industriebetriebe GmbH
Obermarktstrasse 48
6410 Telfs - Austria
Contact person: Maria Koch
Phone: +43 5262 6903-503
Fax: +43 5262 6903-8503
Mail: maria.koch@thoeni.com
Website: www.thoeni.com



TSP – Thöni Screw Press

Cutting-edge technologies for waste treatment and renewable energy production

Thöni has been involved in the development of innovative plant technology for waste treatment and biogas production from organic waste and feedstock since 1990. We offer turnkey systems from project development through engineering, manufacturing and construction, to commissioning and maintenance. Thöni engineers and designs these high-tech systems at its company headquarters in Telfs

thöni



(AT) and manufactures the plant components in the company's own manufacturing facilities at Landeck (AT). The Thöni screw press (TSP) is specialty suited for the dewatering of digestion residues with an extremely wide dry substance content. Currently, more than 150 Thöni presses are in operation all over the world. The latest innovative solution – vibrating screen in combination with Thöni press – significantly increases the separation efficiency. Thöni is one of the largest suppliers of high solids dry digestion plants.



- ▶ Digestion technology
- ▶ Waste treatment
- ▶ Service and maintenance
- ▶ Feedstock preparation
- ▶ EPC contractor

Year of foundation **1951**
Number of employees **900**

Eggersmann Gruppe GmbH & Co. KG
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Digestate Conditioner BRT HARTNER DCD

The Eggersmann Group is one of the leading plant and special machine suppliers for the waste management industry and possesses decades of experience in the field of mechanical and biological (aerobic and anaerobic) waste treatment methods and processes.

The dry fermentation plants of the company BEKON, which belongs to Eggersmann, enable the production of biogas from organic waste or biomass and, at the same time, provide the raw material for composting that follows in the process chain.

 **Eggersmann**



In addition to plant engineering, Eggersmann is an accomplished manufacturer of mobile and stationary special machines for waste management. Renowned brands such as BACKHUS, BRT HARTNER, CONVAERO, FORUS, Terra Select and TEUTON belong to Eggersmann as well and supply solutions for a wide range of process areas such as composting, opening, dosing, bunkering, drying, mixing, shredding, screening or sifting.



MKR vacuum evaporator DV1000

As a family-run company in the second generation, we have been offering vacuum evaporators for treating digestate since 2010, and can rely on over 25 years of experience in industrial fluid treatment. All the key components are manufactured at the Monheim site.

Service performances at short notice are always ensured via our service network. We cover a wide range of digestates with the RT and DV model ranges. The evaporators can be operated flexibly, have a modular design and can be subsequently expanded.

With a heat consumption of 190 to 600 kW and a distillation capacity of up to 4.4 l/kWh, up to 70% water can be extracted from the digestate. At the same time up to 80% of the ammonium-nitrogen is converted into an ammonium sulphate solution (ASL) and an odour-free, dischargeable distillate is produced.

Over 25 evaporators already prove our efficiency. We would be happy to also be your partners in treating digestate.



- ▶ Service and maintenance
- ▶ Flexible waste heat utilisation
- ▶ Nitrogen reduction
- ▶ ASL production
- ▶ Digestate reduction

Year of foundation **1990**
Number of employees **55**

MKR Metzger GmbH
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Application technologies



HOLMER Terra Variant 435 with 16 m³ slurry tank

HOLMER Maschinenbau GmbH is a modern, medium-sized mechanical engineering company that develops, produces, sells and services agricultural machines. HOLMER has its headquarters in Eggmühl (Germany). With subsidiaries in France, Poland, the Czech Republic, Ukraine, Turkey and the US, as well as a representation in China, the HOLMER team consists of more than 400 employees. All machines are manufactured in the plant in Eggmühl. The HOLMER machines are in successful operation in over 45 countries world-wide.

HOLMER Maschinenbau GmbH is the world market leader for self-propelled sugar beet harvesters.

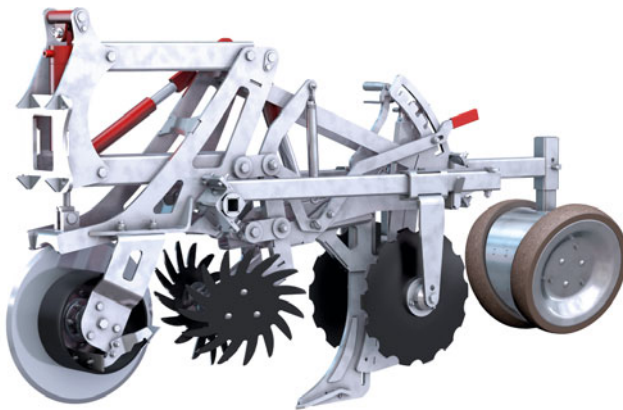
HOLMER has also been successful in the fields of organic fertilization and field logistics with the Terra Variant for more than 20 years. The Terra Variant 585 is available with slurry or spreading superstructure – this carrier tractor stands for efficiency through power. The “small” Terra Variant 435 is a slurry tanker for everyone with its 16 m³ superstructure.



- ▶ Soil incorporation
- ▶ Self-propelled spreader
- ▶ Self-propelled slurry tanker
- ▶ Organic fertilisation

Year of foundation **1969**
Number of employees **400**

HOLMER Maschinenbau GmbH
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Vogelsang Strip Till Machine XTill



Vogelsang dribble bar system SwingMax



- ▶ Dribble bar system
- ▶ Trailing shoe system
- ▶ Strip Till
- ▶ Pump technology
- ▶ Precision distributors

Year of foundation **1929**
Number of employees **900**

Vogelsang GmbH & Co. KG
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Website: www.vogelsang.info

Vogelsang GmbH & Co. KG (www.vogelsang.info) develops, produces and sells technical high-quality and easy-to-maintain machines worldwide. Its head office is located in Essen/Oldb. in Lower Saxony, Germany. Founded in 1929, as a manufacturer of agricultural machinery, the company has grown to become a specialist in individual configurable machines, plants and systems for the waste water, agriculture, biogas, industrial and transportation sectors with over 900 employees worldwide.

The company offers products for economical digestate management, and its invention of the dribble bar system and precision distributor has played a major role in modern precision liquid manure spreading technology. Vogelsang has developed dribble bar systems for tankers, self-propelled vehicles and umbilical systems. The dribble bar system deposits digestate close to the soil under the plant, which is thus, optimally supplied with all nutrients.



This allows the user to significantly reduce nutrient emissions. Among other things, the Vogelsang precision distributors and a clever hose layout ensure the highest distribution accuracy during liquid manure spreading, so that plants are evenly supplied with the important nutrients. The stable end hoses ensure that the digestate is spread under the crops while still adapting flexibly to the soil conditions.

Robust frame designs ensure durability. The Vogelsang dribble bar systems are designed for working widths of up to 36 metres. This reduces passages and has a gentle effect on the soil. Thanks to flexible management of part-width sections, these linkages can also be flexibly adapted to various working widths. In addition, Vogelsang has the SwingUp Slide trailing shoe systems with a working width of up to 18 metres and SwingMax Slide with up to 30 metres in its portfolio. In individual cases, retrofitting of existing dribble bar systems is also possible.

With the Strip Till process, Vogelsang has placed another innovation on the market. With the XTill ProTerra, Vogelsang was one of the world's first suppliers of a fully developed unit that combines Strip Till technology with root-level liquid manure fertilization. With the XTill VarioCrop, Vogelsang added a Strip Till unit for any type of crop with root-level liquid manure fertilization to the XTill product family.

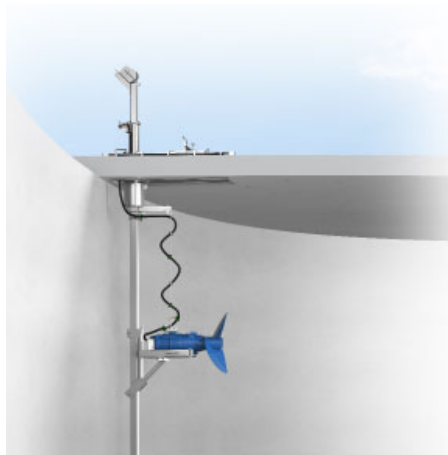
As a partner for the digestion phase, Vogelsang advises consultants, planners and operators of biogas plants and supplies pumping, shredding, disintegration and solid matter feeder technology for economical and efficient plant operation.



Qualität setzt sich durch - seit 1887



The company Franz Eisele u. Söhne GmbH & Co. KG is a manufacturer and producer of pumps, agitators and many other components for biogas, agriculture and industry. Eisele supplies customers all over the world who are impressed with the proven quality and reliability. The products are produced using new technologies at the Sigmaringen factory. In addition to a smooth production process, great value is placed on customer service. The many years of experience of Eisele and the competence of their employees are the most important part of this.



Submersible mixer GTWSI-EX with pass through tube

It is enthusiasm and the passion for perfection and the loyal support of our customers, which makes these achievements possible. Made in Germany – quality prevails – since 1887.



- ▶ Agitator technology
- ▶ Components for biogas
- ▶ Components for agriculture
- ▶ Pumping technology

Year of foundation **1887**
Number of employees **100**

Franz Eisele u. Söhne GmbH & Co. KG

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The Sewerin group of companies

The Sewerin group of companies is an internationally successful, technically innovative, family owned group with headquarters in Gütersloh, Germany. With top level products and services, they are the market technology leader and a partner to the (bio) gas and water supply industry. Together with their over 90 years of experience in the development of measuring devices, the knowledge accumulated by their own measuring teams contributes significantly to their success. At the Gütersloh location, the innovative devices for leakage detection and analysis of biogas move through development, design, testing and production before they are finally ready for the market. Throughout this, there is a particular emphasis on high quality and func-



Multitec BioControl system with permanently installed BioControl and mobile Multitec 540

tionality. An important factor of success is production in Germany. In addition to the sale of measuring devices and services offered by the gas and water leak detection teams, the Sewerin group of companies offers stationary and mobile device maintenance service, development of emergency and leakage service vehicles and servicing and repair of home installations. In addition, a comprehensive programme of seminars with test track rounds off the spectrum of services. An extensive distribution network consisting of sales engineers, subsidiaries and distribution partners in over 80 countries enables success on a global level.



- ▶ Gas quality measurement
- ▶ Gas volume measurement

Year of foundation **1923**
Number of employees **300**

Hermann Sewerin GmbH

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Website: www.sewerin.com



- ▶ Digestate marketing
- ▶ Digestion technology
- ▶ Biochar
- ▶ Humus formation
- ▶ Terra Preta

Year of foundation **2013**
Number of employees **3**

EnergiEffekte GmbH

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Website: www.energieeffekte.de



Anaerobic digestion is our passion!

Dr Melanie Koch, Sina Beckmann and Thomas Redwanz founded the EnergiEffekte GmbH in 2013 – the portfolio extends beyond consulting for biogas plants with various additives and products (own liquid trace element mixtures, iron products, sodium bicarbonate, etc.) to others services in the digestate and sewage sector.

Especially the processing of digestate is at the center of attention. Some projects on this topic are in the planning and implementation phase.

EnergiEffekte



EnergiEffekte brings together project partners, supports biogas plant operators and plans digestate concepts individually.

Another topic is the production of biochar and the support of the farmers in humus production. In addition, the planning and consulting company offers comprehensive care contracts with monthly laboratory analyses, biological and technical consulting as well as the entire process management of biogas plants. Further information can be found at www.energieeffekte.de.

You can expect:

- » Current lectures from the industry for the industry
- » Exclusive workshops
- » Biogas worldwide: case studies, best practice, regulations and market drivers from all corners of the world
- » Topics: security, efficiency, legal requirements for biogas plants, use of digestate as fertilizer, biomass production, repowering and future projects



BIOGAS Convention

The worldwide biggest meeting of the biogas industry

November – every even year
at Hanover
together with the Trade Fair:



December – every uneven year
at Nuremberg
BIOGAS Convention & Trade Fair:



Current information:
www.biogas-convention.com



Presentations in German or English
or with simultaneous interpretation



Organisations

Fachverband Biogas e.V.

The German Biogas Association unites operators, manufacturers and planners of biogas plants, representatives from science and research and all those interested in the industry. Since its establishment in 1992, the association, which currently has more than 4,800 members, has become the most influential independent organisation in the field of biogas worldwide. It campaigns for the increased use of biogas and biomethane technology through political lobbying at EU, national and state levels. Furthermore, it encourages the exchange of biogas-related information and knowledge, for instance by collecting, evaluating and spreading knowledge of scientific findings and practical experience, or by means of conferences, exhibitions and other events.

Fachverband Biogas e.V. works closely with international organisations such as the Deutsche Gesellschaft für Internationale Zusammenarbeit [German Association for International Cooperation] (GIZ), the United Nations Industrial Development Organisation (UNIDO), the International Solid Waste Association (ISWA) as well as the European Biogas Association (EBA), where it also acts as a founding member. As a consequence, Fachverband Biogas e.V. actively promotes and stimulates the exchange of international experience.

Fachverband Biogas e.V. has excellent expertise and knowledge in all biogas-related topics and cooperates with almost all official German bodies as well as many international ones where standards for biogas plants are discussed, developed and defined.

Year of foundation: **1992** | Number of employees: **41**



Fachverband Biogas e.V.

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Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

The Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH is a global service provider in the field of international cooperation for sustainable development. GIZ has over 50 years of experience in a wide variety of areas, including economic development and employment, energy and the environment, and peace and security.

As a public benefit federal enterprise, GIZ supports the German Government – in particular the Federal Ministry for Economic Cooperation and Development (BMZ) – and public and private sector clients in around 120 countries to achieve their objectives in international cooperation. With this aim, GIZ works together with its partners to develop effective solutions that offer people better prospects and sustainably improve their living conditions.

Year of foundation: **2011** | Number of employees: **19,506**



Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

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Indian Biogas Association

The Indian Biogas Association (IBA) is the first nationwide and professional biogas association for operators, manufacturers and planners of biogas plants, representatives from public policy, science and research in India. Currently, the association has members from all across the biogas community and related fields involved in promoting biogas. They represent industry, individuals from academia, institutes, government and non-government organisations contributing directly or indirectly to the biogas vision of India set forth by IBA.

The efforts of IBA have been towards building a strong platform, which would prove to be instrumental in the growth of the biogas sector. IBA aids its members and the biogas community in exploring the sector at the national and international level. Through political advocacy at the centre and state level, IBA promotes the drafting and adoption of conducive policy and programmes pertinent to the biogas sector. Furthermore, it actively disseminates awareness through participation in workshops, conferences, trade shows, and seminars, organises training programmes across India, and engages in experience sharing and sectoral update via its periodic newsletters, magazines and brochures.

Established in 2011, IBA presently has its headquarters in Gurgaon, India, and is represented by a four-member board, all having significant experience in the renewable energy sector. It has around 130 members from across India, with representatives from the international community as well.

Year of foundation: **2011** | Number of employees: **6**



Indian Biogas Association

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European Compost Network (ECN) e.V.

The European Compost Network (ECN) is a European non-profit membership organisation promoting sustainable recycling practices in composting, anaerobic digestion and other biological treatment processes of organic resources. ECN represents more than 3500 experts and plant operators with more than 33 million tonnes of biological waste treatment capacity.

ECN's vision is a Europe in which all organic resources are recycled and recovered in a sustainable way. Following this vision, ECN's primary goal is to support the implementation of EU waste policies, thereby contributing to the development of a recycling society, sustainable agriculture and energy recovery, improved human health, and creation of overall added value within the European market. To achieve this, we believe that effective recycling across Europe should be built on appropriate collection systems for organic waste to promote high quality products derived from biological treatment. ECN supports this development by implementation programmes for member states, development of EU quality assurance systems for compost and digestate, and guidelines for monitoring operational processes within compost and digestate facilities.

Year of foundation: **2000** | Number of employees: **2**



European Compost Network ECN e.V.

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Glossary

Aerobic digestion: Biological degradation processes that occur in the presence of oxygen. Examples are composting and nitrification.

Anaerobic digestion: Biological degradation processes that occur when oxygen is not present, because the microorganisms involved do not require oxygen for their metabolism or can be inhibited or killed by it. Examples are biogas production and denitrification.

Ammonia (NH_3): Pungent smelling and toxic gas which is chemically balanced with ammonium depending on pH value and temperature.

Ammonium (NH_4): Mineralised nitrogen compound used as a fertilizer available for plants.

Ammonium sulphate solution is produced in an acid scrubber by binding NH_3 to sulfuric acid and can be used as mineral fertilizer or mixed back into the liquid digestate.

Flocculants: Operating aids used to achieve higher solid separation during separation. This creates an agglomeration of the particles contained in the digestate and thus improves the separation.

Nitrification and denitrification: Nitrification is the aerobic (aerated) conversion of NH_4 or NH_3 via nitrite to nitrate. Denitrification is the anaerobic conversion of nitrate to atmospheric nitrogen (N_2).





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SYMBOL DESCRIPTION:

Animal by-products



Vegetable by-products



Biowaste from households



Industrial and commercial wastes



Energy crops



Wet continuous digestion



Dry continuous digestion



Dry batch digestion



Digestate



Biomethane



Electricity



Heat/cold



Fuel



Direct application



Laboratory/Measuring



Separation



Composting



Drying /
Atmospheric evaporation



Pelletising



Vacuum evaporation



Membrane filtration



Precipitation



Stripping



Waste water treatment



The depicted symbols are used consistently throughout the brochure and as a classification system for the different companies in the directory.



Fachverband
BIOGAS

German Biogas Association
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