Factsheet
SYSTEMIC demonstration plant

# BENAS (Ottersberg, Germany)

## A short introduction to BENAS

The SYSTEMIC demonstration plant of BENAS (Figure 1) is located in the north of Germany, near Bremen. The plant has a processing capacity of 174 kilotonnes (kt) feedstock per year divided over four digesters and three storage tanks. BENAS also owns 3,500 hectares of arable land (1,000 ha near Ottersberg), has 35 employees and its own truck fleet.

*Table 1. Technical information of the biogas plant.*

| Characteristic | |
|---|---|
| Year of construction | 2006 |
| Maximum power output | 11.3 $MW_e$ |
| Digester volume | 39 100 $m^3$ |
| Digestion type | Thermophilic digestion |

## Drivers for nutrient recycling

Chicken manure is readily available in the region as a feedstock for biogas plants at a relatively low price to be paid to the farmer. However, due to ammonia ($NH_3$) inhibition of the anaerobic microorganism, it is a difficult feedstock to digest. Restrictions on nitrogen (N) application on agricultural land make its disposal difficult. This leads to high transportation cost due to large transport distances.

*Figure 1. Aerial photo of the demonstration plant BENAS.*

BENAS has been forced to search for a digestate processing technology that lowers the $NH_3$ content of the digestate, recovers N and reduces the amount of digestate for field application. The plant director owns arable land, 200 km from Ottersberg, which is fertilised with fertilisers produced by BENAS from digestate. Trucks bring the fertilisers to the arable land and drive back to Ottersberg with energy crops that are used as feedstock for the digester. BENAS benefits from the investments in nutrient recovery and reuse technologies: higher biogas production and a larger feedstock share of chicken manure due to $NH_3$ stripping, lower stripping costs due to the use of gypsum instead of acids for scrubbing of $NH_3$ and revenues from selling the produced low-N fibres.

## Feedstocks

The co-digestion capacity is 174 kt feedstock (organic substrate) per year. In 2019, the plant digested about 92 kt feedstock, of which 86% was crop material and 14% was chicken manure (Table 2).

*Table 2. Origin of BENAS' digester feedstock (2019).*

| Type | Mass (kt) |
|---|---|
| Maize silage | 41 |
| Other crops | 37.9 |
| Chicken manure | 13.3 |
| **Total** | **92.2** |

## Biogas production

In 2019 around 20 Mio $Nm^3$ of biogas were produced (Table 3). About 12 Mio $Nm^3$ were converted in the combined heat and power (CHP) installation into electrical (27,993 MWh) and thermal (25,518 MWh) energy. About 8 Mio $Nm^3$ were upgraded to biomethane, which corresponds to an energy production of 37,699 MWh.

*Table 3. Biogas production and average biogas composition before purification for the year 2019.*

| Parameter | Amount |
|---|---|
| $CH_4$ (% v/v) | 53 |
| $CO_2$ (% v/v) | 46 |
| $H_2S$ (ppm) | 83 |
| $O_2$ (% v/v) | 0.1 |
| Total biogas production ($Nm^3$) | 20.4 Mio |
| Biogas per tonne of feedstock ($Nm^3$ $t^{-1}$) | 222 |

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## Nutrient Recovery & Reuse (NRR) process

After storage in the post-digesters, the digestate is separated by the first screw press in a liquid fraction (LF) and solid fraction (SF) which both are applied on agricultural land. A second way of processing is also possible: in an internal recirculation loop, digestate is fed to the FiberPlus system for removal of $NH_3$ (detailed description below). In this system, $NH_3$ and carbon dioxide are brought into contact with gypsum resulting in ammonium sulphate solution and calcium carbonate sludge (Figure 2). The produced N-stripped digestate is separated into an SF and LF, the latter is fed back to the digester. The SF is further processed in a fibre moulding and paper making machine. The resulting product is dried, with excess heat from the CHP installation to remove residual moisture, to the end product low-N fibres. The fibres are suitable for different applications such as production of paper, mulch mats or plant pots.

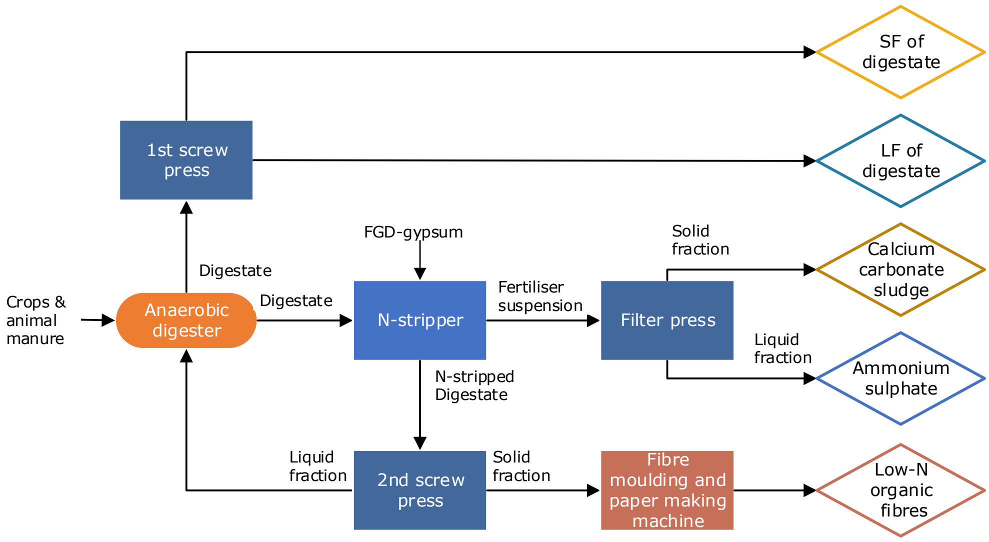


*Figure 2. Simplified process flow diagram of BENAS's current nutrient recovery and reuse system.*

## N-stripping and scrubbing process (FiberPlus system)

In 2007/2008, BENAS installed the FiberPlus system, developed and patented by GNS, in which $NH_3$ is stripped from digestate without the use of acids, bases or external stripping agents (Table 4). The system consists of an N-stripper and scrubber, filter press and the second screw press. It requires the addition of Flue Gas Desulphurisation-gypsum (FGD-gypsum) to produce two marketable fertilisers: ammonium sulphate solution, with a dry matter content of 22–26%, and calcium carbonate sludge, with a dry matter content of circa 75%. The process does not require an external heat source as it functions solely on the heat produced by the CHP installation. It consumes circa 100 kWh of thermal energy per $m^3$ of digestate processed. The added FGD-gypsum is a by-product of coal power plants. From 2011 onwards the N-stripped digestate or its LF is fed back to the digester. The advantages of the FiberPlus system are:

- Of the $NH_3$ in the digestate, 56–85% is stripped and subsequently recovered as ammonium sulphate solution and partly as calcium carbonate sludge;
- $NH_3$ inhibition of the digester is prevented, increasing the biogas yield by 8%;
- Since October 2016 the FiberPlus system has been expanded with the production of low-N fibres.

*Table 4. Technical specifications of the FiberPlus system.*

| Specification | |
|---|---|
| Digestate processing capacity | 5–25 $m^3$ $h^{-1}$ |
| $NH_3$ content of ingoing digestate | 3–5 g $L^{-1}$ |
| Dry matter content of ingoing digestate | 5–12.5 % |
| $NH_3$ striping efficiency | 56–85% |
| Production capacity of ammonium sulphate solution | 5–40 t $d^{-1}$ |
| Production capacity of calcium carbonate sludge | 1.5–14 t $d^{-1}$ |

*This project has received funding from the European Union's H2020 research and innovation programme under the grant agreement No: 730400. SYSTEMIC started 1 June 2017 and ran for 4 years.*

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## Status of construction

To make the plant's electricity generation more flexible in time, BENAS has installed an additional biogas storage tank. Also, two additional CHP installations have been installed and all digesters and storage tanks have been fitted with new roofs.

## Products and market

In 2019, BENAS produced 1,128 t of calcium carbonate sludge, 3,545 t of ammonium sulphate solution and <1 000 t of low-N fibres. The composition of the ingoing digestate and produced end products is given in Table 5.
The ammonium sulphate solution is recommended by GNS as a good fertiliser because:

- its neutral pH is well tolerated by plants;
- its dry matter content of 22–26% does not lead to evaporative crystallisation when applying it directly on crops;
- It can be used for producing mineral fertiliser solutions or for increasing the N content of manure or digestate.

Also, the field application of calcium carbonate sludge has the following advantages:

- calcium is an important plant nutrient;
- it increases soil pH and enhances nutrient availability without causing alkalinisation because it dissolves only in acidic soils;
- it improves soil structure and soil biological activity.

*Table 5. Composition of the ingoing digestate and produced end products at BENAS (February 2018 – February 2020).*

| | Digestate | Liquid fraction of digestate | Solid fraction of digestate | Calcium carbonate sludge | Ammonium sulphate solution |
|---|---|---|---|---|---|
| Dry matter (g kg$^{-1}$) | 105 | 94 | 248 | 690 | 221 |
| Organic matter (g kg$^{-1}$) | 83 | 68 | 222 | 29 | 0.35 (TOC) |
| Total N (g kg$^{-1}$) | 7.4 | 7.2 | 7.9 | 13 | 45 |
| Total P (g kg$^{-1}$) | 1.9 | 1.6 | 1.8 | 0.17 | 0.0027 |
| Total K (g kg$^{-1}$) | 6.8 | 6.4 | 8.9 | 0.4 | 0.0059 |
| Total S (g kg$^{-1}$) | 1.2 | 1.0 | 1.4 | 28 | 58 |

## Economic benefits

GNS calculated that the replacement of conventional fertiliser with ammonium sulphate solution and calcium carbonate sludge saves BENAS about € 300,000 per year (Table 6). In addition, the sale of low-N fibres is estimated to generate around € 82,000 of revenues per year. A higher biogas yield is achieved due to reduction of $NH_3$ inhibition. Also, a higher intake of chicken manure, a low-price feedstock due to its high N content, is possible. Due to the lower N content, more SF and LF of digestate can be applied per ha of arable land which results in lower storage and transport costs for BENAS.

*Table 6. Economic benefits of the NRR system.*

| Benefit | € y$^{-1}$ |
|---|---|
| Use of ammonium sulphate solution | 244,000 |
| Use of calcium carbonate sludge | 63,000 |
| Revenues from low-N fibres | 82,000 |
| Higher biogas yield | 321,000 |
| Higher fraction of N-rich digester feedstock | 385,000 |
| Heat utilisation (EEG 2004, Renewable Energy Law) | 176,000 |
| **Total savings** | **1,271,000** |

## Sustainability goals

BENAS is committed to reaching the following targets:

- Decreasing overall greenhouse gas emissions by producing renewable energy and lowering $CO_2$ emissions from transport of digestate or its fractions;
- Contributing to a more stable electricity grid via flexible electricity generation in time;
- Closing the nutrient cycle by using the produced end products on their own fields for production of energy crops';
- Production of low-N fibres as an environmental friendly alternative for wood fibres or peat.

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## Monitoring data: total mass and nutrient mass flows

Total mass (Figure 3) and nutrient mass (Figure 4) flows were calculated for the NRR system of BENAS for the period January 2019 – April 2019. This was done to evaluate the overall performance of the plant and the separation efficiencies of the individual process units. Of the total N in the digestate processed in the N-stripper, 31% ended up in the ammonium sulphate solution and 4.5% in the calcium carbonate sludge. Of the $NH_4$-N in the digestate processed in the N-stripper, 57% ended up in the as ammonium sulphate solution and 7.8% in the calcium carbonate sludge.

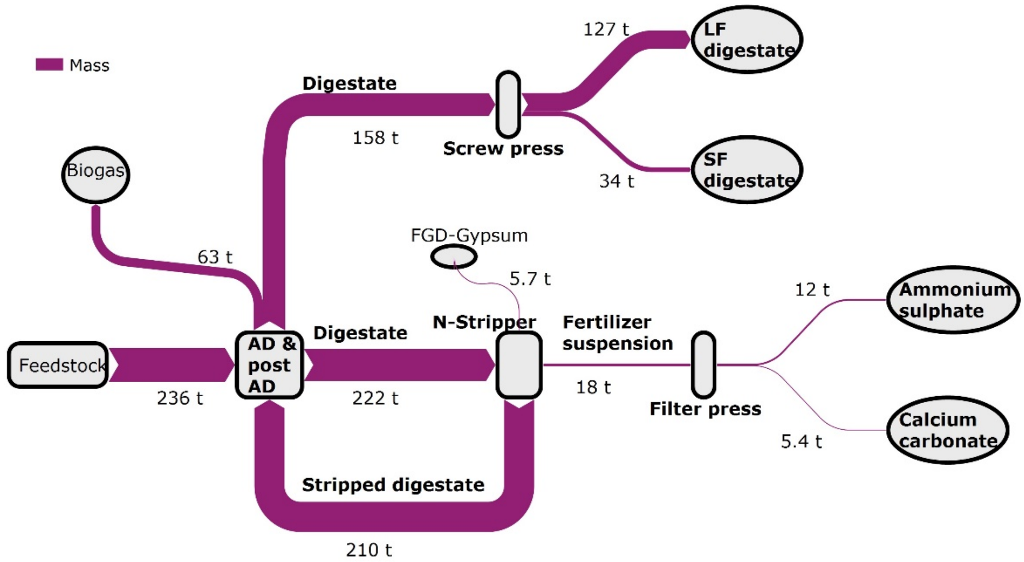


*Figure 3. Total mass flows of the nutrient recovery and reuse system at Benas in tonnes (t) per day.*

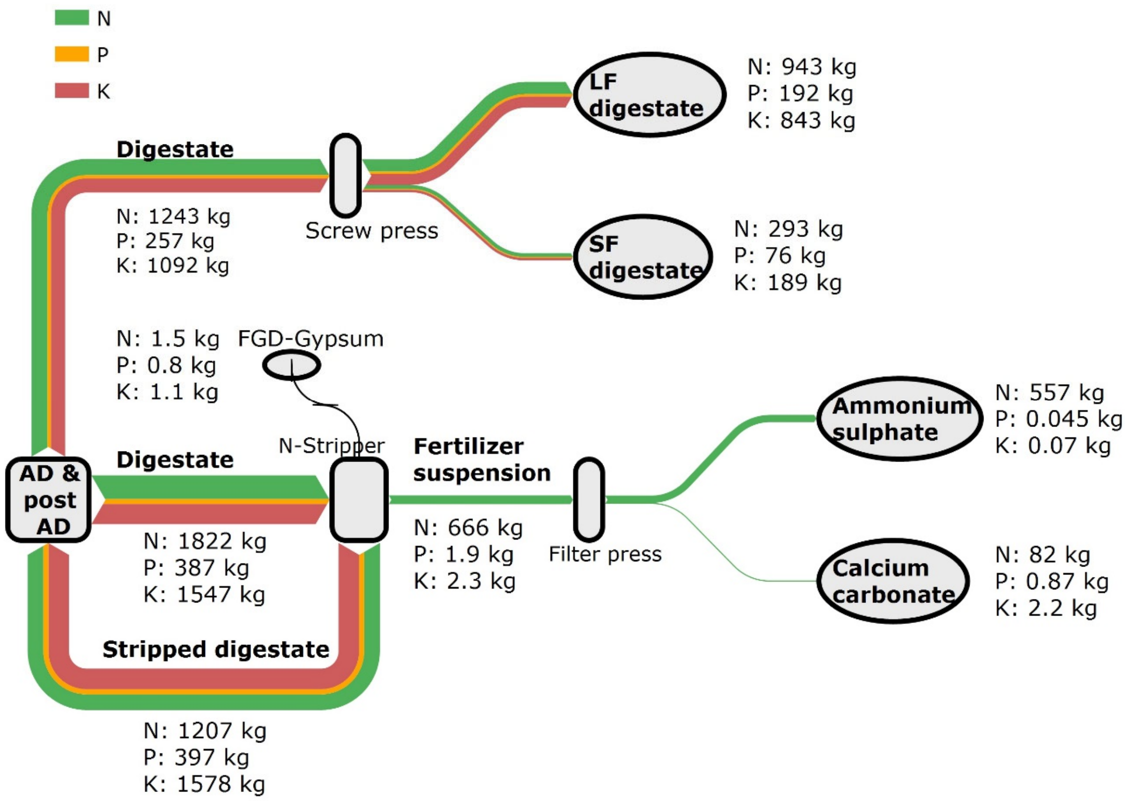


*Figure 4. Total nitrogen (N), total phosphorus (P) and total potassium (K) mass flows of the nutrient recovery and reuse system at BENAS in kilogram (kg) per day.*

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## Monitoring data: energy balance

In 2019 the plant generated 25,518 MWh of thermal energy, of which 21% was subsequently consumed by the N-stripper. The remainder was used for cooling of the stripping gas and biogas, for heating of the digesters and buildings and for drying of grain and wood chips. The plant generated 27,993 MWh of electricity of which only 6% was used by the plant. The remainder was sold via the national grid (Figure 5).

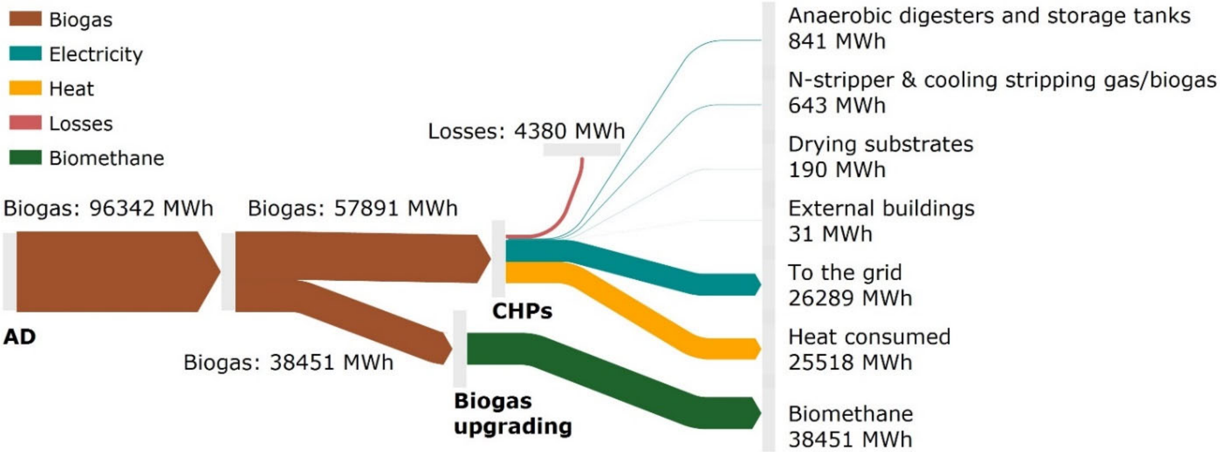


*Figure 5. Energy balance of the anaerobic digestion (AD) and nutrient recovery and reuse system at Benas for the year 2019.*

## Key Performance Indicators (KPIs)

Economic KPIs are simple tools to gain insight into a company's economic performance:

**$KPI_1$**: EBIT (Earnings Before Interest and Taxes) margin as % of revenues.
**$KPI_2$**: EBITA (Earnings Before, Interest, Taxes and Amortisation) margin as % of revenues.
**$KPI_3$**: Substrate (financial) productivity → total gross revenues per tonne of feedstock.
**$KPI_4$**: Biogas (financial) productivity → net revenues of biogas (energy / green certificates) per cubic meter of biogas delivered.
**$KPI_5$**: Digestate (financial) productivity → net costs/revenues generated by digestate per tonne of feedstock.

*Table 7. Economic KPIs of BENAS's plant.*

| KPI | |
|---|---|
| EBIT margin | 13% |
| EBITA margin | 36% |
| Substrate productivity | €80 / tonne feedstock |
| Biogas productivity | €0.38 / Nm$^3$ biogas |
| Digestate productivity | €-0.95 / tonne feedstock |

The high biogas productivity of the plant results in the highest substrate financial productivity of all SYSTEMIC demonstration plants. However, the high total costs for insurance, maintenance, personnel and consumption of electricity and FGD-gypsum have a large impact on the EBIT and EBITA.

More information on the economic KPI analysis is available in deliverable D2.4: *'Final report on the development and application of economic key performance indicators (KPIs)'.*

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