Groot Zevert Vergisting (Beltrum, NL)

A short introduction to GZV

Groot Zevert Vergisting (GZV), located in Beltrum (the Netherlands), started its biogas activities in 2004 (Figure 1). The company nowadays treats about 135 kt of feedstock through mesophilic digestion.

In 2019, GZV started with the production of biobased fertilizers, soil improver and clean water from digestate. In doing so, they aim to offer a sustainable solution to the manure surplus in their region.

Figure 1. Demonstration plant GZV

Drivers for Nutrient Recycling

In the Netherlands, manure production by livestock is greater than the amount that can be applied on agricultural soils. Manure application is regulatory limited by both its phosphorus and nitrogen content. The surplus amount of pig manure, about 30% in the Netherlands, is transported to other countries, mostly Germany. The transport of large volumes of manure over distances of 200-400 km is costly. As a consequence, farmers are faced with high costs for manure disposal (€ 25,- per ton pig manure).

As a solution to the manure surplus in the region, GZV decided to invest in nutrient recovery technologies converting digestate into valuable biobased fertilisers:

- Nitrogen potassium (NK) concentrate to be used within the region
- Clean water to be discharged in a nearby stream
- Organic soil improver with a low nutrient content
- P fertiliser to be used as an ingredient for the production of mineral fertiliser at ICL Fertilizers.

These biobased fertilisers can be used within the region or can be exported over long distances against low costs. The separation process is therefore expected to generate substantial costs savings.

Feedstock and biogas production

The co-digestion plant treats 100 kt of manure and 35 kt of co-products (Table 1). Pig manure is collected from about 55 pig farms in the region. About 80% of the biogas is used by a nearby dairy factory of Friesland Campina. which is connected to GZV via a 5 km long pipeline. The other 20% is converted to electricity and heat and mostly used on-site (Table 2).

Table 1. Feedstocks of the GZV digester (2018)

Type	Origin	Mass
Manure	Pig manure	80 kt
	Dairy manure	5 kt
	Slaughterhouse manure	15 kt
Co-products	Waste dairy industry	15 kt
	Waste feed industry	15 kt
	Glycerin	5 kt
Total		**135 kt**

Table 2. Biogas production (2018)

Component	
CH_4 (%)	56
CO_2 (%)	40
H_2S (ppm)	1000-2000
O_2 (%)	0.2
Total biogas production (Mm^3)	9
Biogas per tonne of feedstock (m^3/t)	78

The nutrient recovery technologies

Digestate is separated into a solid and a liquid fraction by a GEA decanter centrifuge. The solid fraction is hygienised by heating it with infrared heaters. The nutrient recovery treatment process consist of two independent units for treatment of the liquid fraction (GENIUS process) and the solid fraction (RePeat process).

Groot Zevert Vergisting (Beltrum, NL)

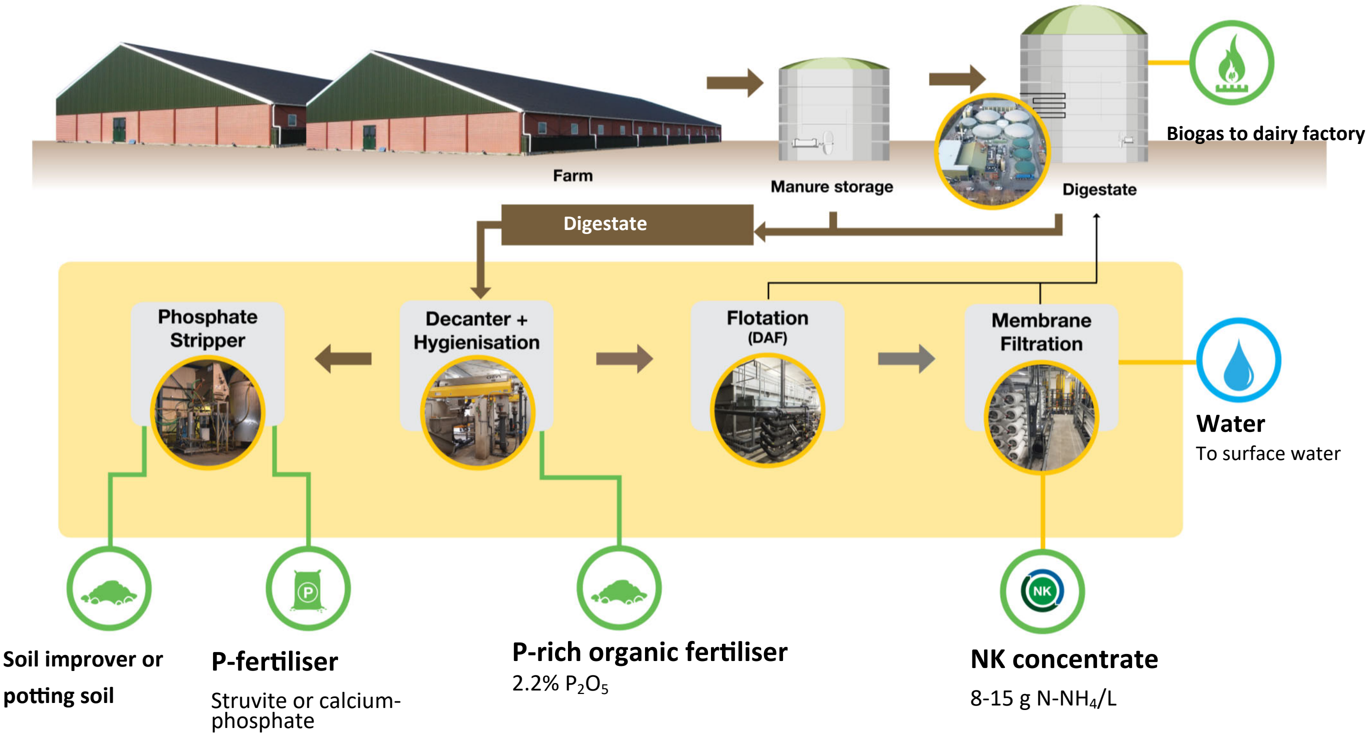

Figure 2. Flow scheme of nutrient recovery system at GZV

GENIUS technology: From liquid manure to NK concentrates and clean water

In the GENIUS process, digestate is separated into a solid and a liquid fraction by means of a decanter centrifuge (Figure 4). The liquid fraction is further processed into an NK concentrate and clean water through a combination of dissolved air flotation (DAF), micro filtration (MF) and reverse osmosis (RO). The NK concentrate contains 8-15 g N L^{-1} as NH_4 and 8-15 g K_2O L^{-1}. The water is being treated by ionic exchange (IX) unit to meet criteria for discharge on surface water.

The RePeat process: Separating P and organic matter

In the **RePeat** process (figure 3), P will be recovered from the P-rich solid fraction of digestate. The solid fraction is mixed with water and thereafter acidified to pH 5 using sulphuric acid. At this pH, nearly all P dissolves. The dissolved P can be separated from the solid fraction by separation with a screw press. Subsequently, P is recovered from the acid liquid through addition of a base, preferably $Mg(OH)_2$, to form struvite crystals. Apart from $Mg(OH)_2$, also other bases such as $Ca(OH)_2$ may be used though the latter produces an amorphous precipitate which requires an additional separation and drying step. The solid fraction is treated in two sequential leaching steps during which 90% of the P is removed. What remains is an organic soil improver with a very low P content.

Part of the sulphate, added as sulphuric acid, precipitates with calcium as gypsum which is either recovered together with the P-fertiliser or as a separate organic gypsum-rich sludge that can be used as fertiliser. Water is continuously reused within the process. Hence, creation of an additional waste stream is prevented.

Status of construction

The GENIUS installation has been in operation since early 2019 and composition of NK concentrate is as anticipated. Further optimization steps are now foreseen to increase the water production rate. The RePeat installation will be commissioned in October 2019.

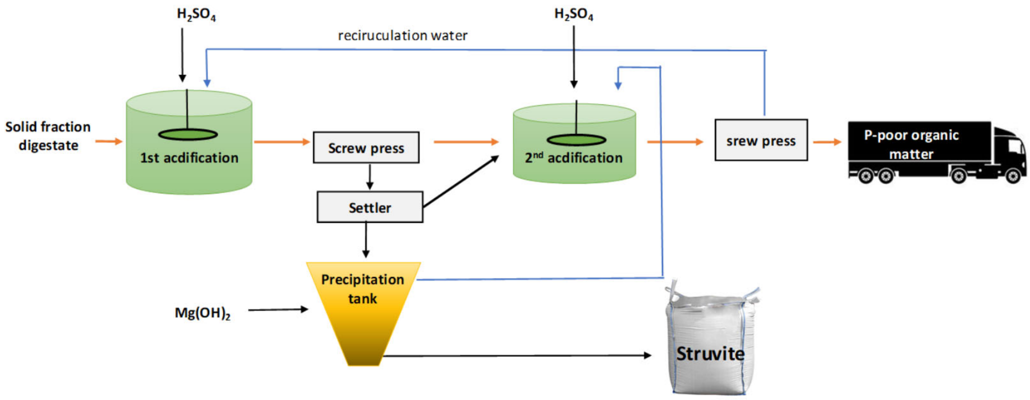

Figure 3. Simplified process scheme of the RePeat process converting solid fraction of manure into P-fertiliser and a soil improver

Products and market

Table 3 gives the envisaged product composition and mass balance. GZV envisages to convert digestate into water (40-50%), NK concentrate, P fertiliser and a soil improver with a low NP content. The production of clean water will substantially reduces costs for manure transport. In 2019, NK concentrate with a N content of about 8 g/kg was produced. It is expected that this will increase to 15 g/kg in the upcoming years.

The NK concentrate is blended with ammonium sulphate or urea to adjust the NKS ratio's to crop demands. The blended product, with the commercial name 'Green Meadow Fertiliser', is used as N fertiliser for grass, maize and potato in the Achterhoek region. GZV initiated the pilot project **Biobased Fertilisers Achterhoek** which allows them to use the blended fertiliser as an alternative for synthetic N fertiliser. In 2019, 50 farmers joined this project and used the Green Meadow Fertiliser above the N application limit of manure in a similar manner as synthetic N fertiliser is used. For this purpose, new equipment for low-emission field application has been developed.

The pilot project Biobased Fertilisers Achterhoek will generate data on the agronomic performance and nitrogen use efficiency (NUE) of the biobased fertilizers applied. These data will serve the current political debate within the EU (SAFEMANURE) about the possible acceptance of N-fertilizing products from manure as alternatives for synthetic fertilizers under the Nitrates Directive.

The recovered P fertiliser can be used as feedstock for production of organic or mineral P fertilisers. The organic matter is low in nutrients and can be used as soil improver or as ingredient for potting soil for the consumer market. Produced water after IX is discharged on surface water.

Table 3. Envisaged mass balances and product quality

Parameter	Unit	Ingoing digestate	GZV Recovered products			
			NK-fertiliser	Soil Improver	P-fertilizer	Clean water
Mass	(%)	100	20-35	10-15	1-2	40-55
Dry matter	(kg/ton)	72	46	320	800	-
Organic Matter	(kg/ton)	52	18	290	320	-
N	(kg/ton)	6.5	8-15	5.0	20	<6 mg/L
$N-NH_4$	(kg/ton)	4.6	8-15	<1	-	<2.5 mg/L
P_2O_5	(kg/ton)	3.5	0.2-0.4	3.2	140	<0.6 mg/L
K_2O	(kg/ton)	4	10-15	0.2	5	<400 mg/l

Sustainability goals

- Balanced fertilisation with products from manure
- Replacement of synthetic N fertiliser by biobased fertiliser containing 10-15 g L^{-1} N-NH_4
- Recovery of the non-renewable element P in a valuable fertiliser to be used elsewhere
- A substantial decrease in CO_2 emissions associated with transport

Monitoring results

The energy balance of GZV for 2018 is given in Table 4. About 75-80% of the biogas produced is sold to a nearby dairy factory. About 13% of the energy contained in biogas is used on site as electricity (4%) and as residual heat (9%) from the CHP. In 2018, GZV disposed of their digestate without any separation step. A mass balance for 2018 is therefore not included.

Table 4. Energy balance for GZV (data 2018)

Energy balance digester and NRR	2018 (no NRR)
Total biogas production (GWh)	50 (100%)
Biogas to dairy factory (GWh)	36 (75%)
Electricity to grid (GWh)	2.6 (5%)
On-site electricity consumption (GWh)	2.0 (4%)
On-site heat consumption (from CHP) (GWh)	4.5 (9%)
Fossil energy consumption (GWh)	0

Factsheet
SYSTEMIC Demonstration Plant

AM-Power (Pittem, BE)

A short introduction to AM-Power

AM-Power (Figure 1) is located in the western part of Flanders (Belgium), a region characterized by an excess of animal manure and a high market demand for synthetic fertilizer. The demonstration plant is the largest biogas installation in Belgium: it has a treatment capacity of 180 kt y^{-1}, spread over four digesters and one post-digester, for the production of 7.5 MW_e of electricity (Table 1).

Table 1. Technical information of the biogas plant.

Characteristics	
Date of construction	2011
Size (MW_e)	7.5
Total volume (m^3)	20 000
Digestion process	Thermophilic digestion

Drivers for Nutrient Recycling

AM-Power has always been experimenting and investing in innovation towards the recovery of nutrients. A long time ago they already envisaged the importance and benefits of moving towards a circular economy. The disposal of digestate represents an important cost for biowaste treatment plants. On top of this, the agro-food industry in Flanders realizes that their waste streams are valuable and thus demand to be paid by biogas plants to retrieve waste.

Figure 1. Overview of AM-Power installation.

Competition between biogas plants makes it difficult to get the turnover break even. AM-Power believes that nutrient recovery can be a way to balance this again.
AM-Power generates every year about 160 kt of digestate and strives to treat it in a cost effective, efficient and relatively simple way, without losing the nutrients. Their technological solution for the recovery of nutrients into valuable fertilizers is currently under implementation.

Feedstocks

In 2018, the co-digestion plant treated 138 kt of feedstock, out of which more than 80% was organic biological waste (industry food waste and source segregated food waste). Co-substrates mainly include animal manure and glycerine (Table 2). Organic biological waste and animal manure are processed in a separate digestion line.

Table 2. Origin of AM-Power feedstock (2018).

Type	Mass
Organic biological waste	112 kt
Manure	12 kt
Glycerine and fat-rich substrates	11 kt
Other feedstock	3 kt
Total	**138 kt**

Anaerobic digestion

- Organic waste is collected and homogenized in a mixing unit to a substance with a dry matter (DM) content of approximately 20%;
- Homogenized feedstock is hydrolysed in a separate unit (with a retention time of 3 days) and fed to a thermophilic digester;
- Retention time is around 50-60 days in digesters and 10 days in the post digester.

Horizon 2020

AM-Power (Pittem, BE)

Biogas production

In 2018, the biogas produced (including digesters and post-digester) was around 14 Mm^3 (Table 3). The biogas is converted by a CHP engine into electrical and thermal energy. The amount of heat and electricity produced was respectively 32 486 MWh_{th} and 29 102 MWh_e.

Table 3. Yearly biogas production and average composition before purification (2018)

Component	
CH_4 (%)	55
CO_2(%)	45
H_2S (ppm)	
O_2 (%)	
Total normal biogas production (Mm^3)	14
CH_4 per tonne of OM (m^3 t^{-1})	206

Nutrient Recovery Technology

The previous process worked as follows:

- Digestate (6% DM) was diluted with liquid fraction (LF) digestate and sent to a decanter centrifuge for solid/liquid separation. Coagulation and flocculation were favoured by the addition of polymer and iron sulphate. Dilution with recirculated LF digestate was necessary for a better efficiency of the reverse osmosis (RO) step.
- The phosphorus (P) rich solid fraction (24% DM) was dried in a fluidized bed dryer. Drying of solid fraction was accomplished by recycling waste heat from CHP engines. The exhaust gas from CHP (160°C) was mixed with air to reach a temperature of 80°C. Dry biosolids (containing 2% total-P and 90% DM) were exported to France where P demand is high.
- The nitrogen (N) and potassium (K) rich LF was first processed in a Dissolved Air Flotation unit (DAF) with the addition of iron chloride and polymer to reduce the DM content of the LF to 1.2 - 1.6% DM. Next, the RO step required the addition of acid (H_2SO_4) to the influent to ensure a good membrane separation. The resulting concentrate, rich in N and K (respectively 0.5% and 0.4%), was used as a fertilizer on local agricultural land. Permeate water was recycled on site.

The novel process includes a continuous multiple effect vacuum evaporator prior the RO, thus increasing the recovery of nutrients from digestate (Figure 2).

- Raw digestate will be mechanically separated in the decanter centrifuge. AM-Power is still investigating the optimal polymer dosage for an efficient evaporation step;
- As in the previous process, the solid fraction (25-30% DM) will be dried up to 90% DM, while the liquid fraction (2.5% DM) will be sent to the evaporator, avoiding the use of energy intensive DAF.
- In the evaporator, the vapour will contain ammonia (NH_3) that is condensed as NH_3 water and subsequently pumped to the RO unit. The concentrated evaporated LF digestate (20% DM) will be blended with the dry solids and applied on agricultural land.
- In the current status, the RO mineral concentrate will be recirculated back to the evaporator, while the permeate water will be discharged to surface water. The recirculated RO mineral concentrate will end up in the concentrated digestate, but it can also be used as a separate product.

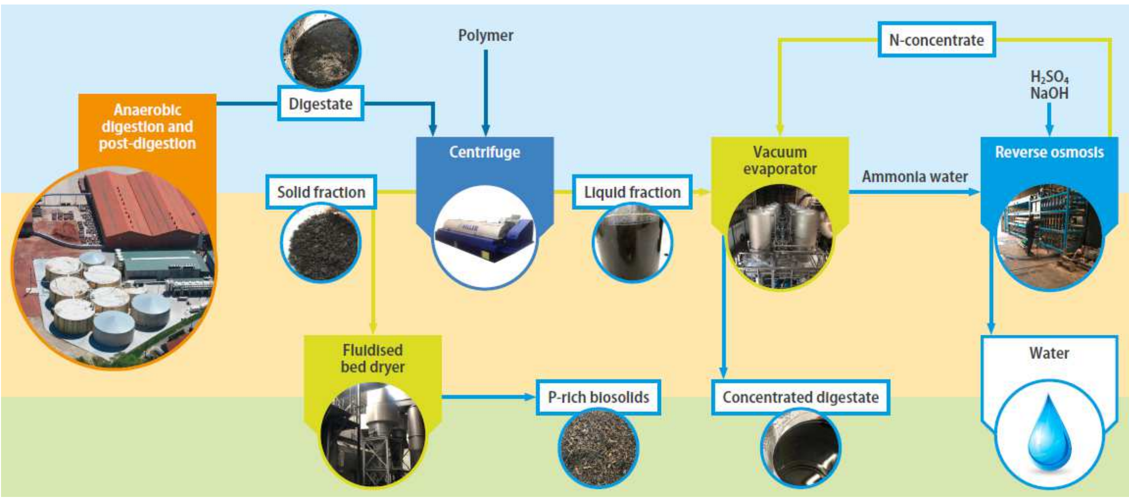

Figure 2. Overview of AM-Power current process scheme.

AM-Power (Pittem, BE)

Status of construction

Figure 3. Overview of the evaporator.

The installation of the vacuum evaporator consists of 2 identical units, each with an evaporation capacity of 150 m^3 d^{-1}. The first vacuum evaporator was delivered in January 2019 and installed to the decanter centrifuge in April. The second vacuum evaporator was delivered in April and installed in June 2019 (Figure 3). Preliminary tests have been conducted on evaporating the LF of digestate and results were encouraging. After evaporation, the DM content of evaporated LF digestate reached 22%, which is 4-5 times higher DM than of raw digestate.
Currently, AM-Power is investigating the optimal polymer dosage required for the best performance of the evaporator. The evaporator manufacturer is finalizing some technical aspects of the unit and implementing the software for the remote control of the system. The investment of the evaporator and adaptation of the process amounted approximately to 2 M€.

Products and market

- The digestate treated with the DAF-membrane system was transformed in P-rich biosolids and mineral concentrate. Mineral concentrate was applied on local fields, whereas P-rich biosolids were exported to France.
- With the novel system, AM-Power is planning to blend the concentrated LF digestate and P-rich biosolids with a ratio 1:1 into an NPK fertilizer to be exported to nutrient depleted regions. Product characteristics are given in Table 4.

Table 4. Composition of the recovered products at AM-Power.

	Previous process (DAF + RO)			Current process (evaporator + RO)	
	Digestate	NK-concentrate	P-rich biosolids	Expected Concentrated LF digestate	Expected P-rich biosolids
pH	8.7	7.7	7.5		7.5
Dry Matter (g kg^{-1})	59	43	912	200	912
Organic Matter (g kg^{-1})	32	18	523		523
N-total (g kg^{-1})	5.5	5	31	7.5	31
NH_4-N (g kg^{-1})	2.9	4.2	0.88		0,88
P-total (g kg^{-1})	1.4	0.01	19	10.2	19
K-total (g kg^{-1})	3.3	4.3	11	9.7	11

Economic benefits

The economic advantages of reusing recovered products are:

- By improving RO efficiency, AM-Power estimated that approximately 150 m^3 of water per day will become available as dischargeable water (after polishing) or used on site. This amount of water does not have to be transported and treated. 36 m^3 per day of water can be additionally removed by drying the solid fraction digestate.
- By replacing DAF, the costs for chemical additives will be drastically reduced.

Sustainability goals

AM-Power is committed to reach the following targets:

- To make high rich nutrient fertilizer products for the market;
- Reduce CO_2 emissions related to digestate transport;
- Reduce the use of additives and chemicals and
- Promote water recycling.

Acqua & Sole (Vellezzo Bellini, IT)

A short introduction to Acqua & Sole

Acqua & Sole (Neorurale group; Figure 1) is an anaerobic digestion plant (AD) located in Vellezzo Bellini (Northern Italy), in an area dedicated to cereal cultivation, mainly rice. Neorurale has a strong focus on nutrient recycling with special attention to the development of an efficient digestate distribution system (direct injection into the soil). The system is being developed in strict collaboration with local farmers with the aim to maximize fertilization effects and minimize ammonia (NH_3) and odour emissions. In addition to the production of soil improvers (digestate), the demonstration plant generates ammonium sulphate (AS) from recovered NH_3 during the digestion step, which is used as nitrogen (N) fertilizer. For the recovery and reuse of nutrients, Acqua & Sole has an ambition of improving soil fertility without any use of synthetic fertilizer over an area of 5 000 hectares (ha), and ensuring the nutrient requirements of the surrounding farms for their annual crop production.

Table 1. Technical information of the biogas plant.

Characteristics	
Date of construction	2016
Size (MW_e)	1.6
Volume (m^3)	13 500
Digestion process	Thermophilic digestion

Drivers for nutrient recycling

Degradation of N-rich feedstock leads to the formation of NH_3 which can have an inhibiting effect on methanogenic microorganisms when reaching toxic levels. Recycling of N as AS becomes a great opportunity for the recovery of nutrients and prevent inhibition of the AD process. Furthermore, low carbon content in soils is an issue in Italy and the utilization of soil improvers (i.e. digestate) is a valuable tool to tackle this. However, restrictions on N application on agricultural land limit their use of organic materials, making it necessary to find solutions to lower their N content of the produced digestate.

Figure 1. Current NRR facility of Acqua & Sole.

Feedstocks

The co-digestion plant capacity is 120 kt organic substrate per year. In 2018, 44 kt were treated out of which about 88% was sewage sludge and 12% was digestate from anaerobic treatment of source-segregated domestic food waste, agro-food waste and liquid fraction of source-segregated food waste (Table 2). The plant can treat manure, expired food, organic wastes, sewage sludge and agro-food industry waste.

Table 2. Origin of Acqua & Sole feedstock (2018).

Type	Origin	Mass
Sewage sludge	Wastewater treatment plants	39 kt
Co-products	Digestate from anaerobic treatment of source-segregated domestic food waste	2 kt
	Agro-Food waste	2 kt
	Liquid fraction of source-segregated food waste	1 kt
Total		44 kt

Acqua & Sole (Vellezzo Bellini, IT)

Biogas production

AD is performed in 3 consecutive digesters of 4 500 m^3 each. The biogas produced by the plant (Table 3) is converted by a CHP engine into electrical (5 000 MWh_e) and thermal (5 800 MWh_{th}) energy. In 2018, about 40% of the electricity produced was consumed by the plant and the remaining 60% was sent to the national grid.

Table 3. Biogas production and average composition before purification in 2018.

Component	
CH_4	55 - 66 %
CO_2	29 - 38 %
H_2S	<10 ppm
O_2	<2 %
Total biogas production	2.3 Mm^3
Specific CH_4 production	203 Nm^3 CH_4 t^{-1} OM

Figure 2. Digestate injection application on fields.

Digestate characteristics

- Thermophilic digestion ensures a better control of pathogenic and intestinal microorganisms in the digestate
- The high N/NH_4-N ratio of the digestate favours long-term fertilization
- Uniformity of digestate distribution is ensured by the digestate injection application approach (Figure 2).

Nutrient Recovery and Reuse (NRR) technology

From April 2016 onwards, the plant operates as following (Figure 3):

- Organic waste (feedstock) is collected in basins located in a closed building to prevent the release of odour. A bio-filter placed on the roof of the building purifies the exhaust air
- Organic waste is moved to a mixing unit where they are heated and homogenized with biomass coming from the third digester
- Homogenized and inoculated feedstock is fed to the thermophilic process (minimum retention time of 20 days and temperature of 55°C) which ensures full sanitation of the incoming sludge
- The process is equipped with a side-stream N-stripping unit, whereby biogas acts as stripping agent. NH_3 is extracted by leading biogas through a H_2SO_4 (about 50%) solution resulting in inorganic ammonium sulphate (AS) production
- Both digestate and AS are stored in steel tank facilities.

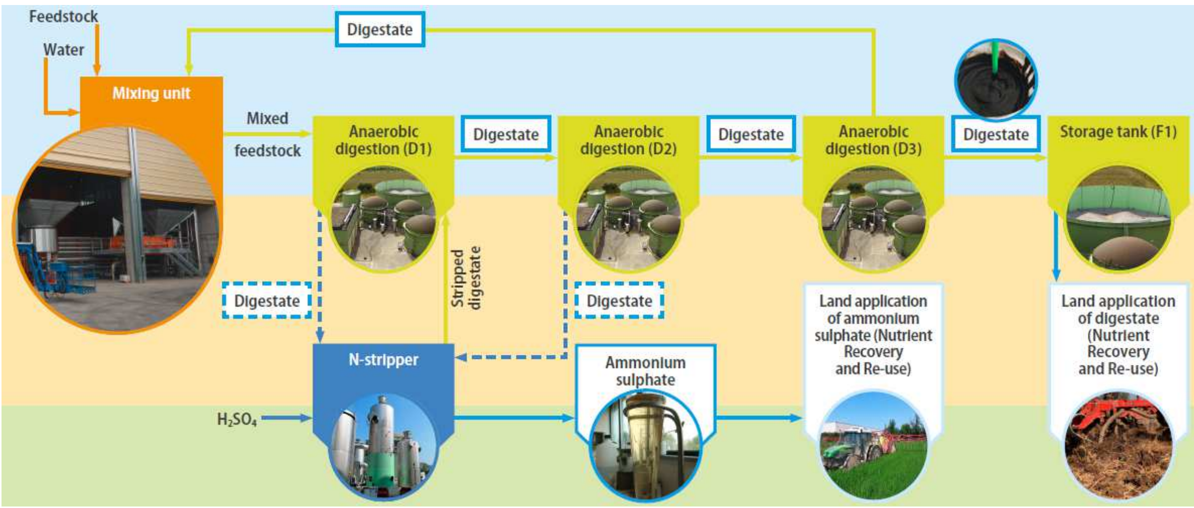

Figure 3. Flow diagram of NRR facility at Acqua & Sole.

SYSTEMIC
Circular solutions for biowaste

Acqua & Sole (Vellezzo Bellini, IT)

Status of construction

The start-up of the plant with the novel N-absorber was scheduled for the end of July 2019. Due to the 6 week delayed supply of AS recirculation pipes (made of alloy 825) Acqua & Sole is still waiting for a declaration of the supplier about this issue. As a result, the construction phase has been delayed. Since the start-up of the new absorption unit has to be coordinated by switching off the existing unit (this transitional period should be as short as possible in order to avoid NH_3 inhibition in the digestion process), the start-up of the new unit has been rescheduled for the end of September/first week of October 2019.

Products and market

The maximum capacity of the co-digestion plant is about 120 kt of organic waste, which will be mixed with water and transformed into maximum 192 kt of digestate. Product characteristics are given in Table 4.

Acqua & Sole estimated that the use of digestate could replace the following maximum amount of synthetic fertilizers: 1550 t y^{-1} of N, 1160 t y^{-1} of P_2O_5 and 170 t y^{-1} of K_2O.

Table 4. Composition of the recovered products at Acqua & Sole (average data January 2018 – March 2019, n=10).

	Digestate	Ammonium Sulphate
Dry matter (g kg^{-1})	101	363
Organic matter (g kg^{-1})	61	-
N-total (g kg^{-1})	7.8	74
P-total (g kg^{-1})	2.8	0.011
K-total (g kg^{-1})	0.63	0.012

Economic benefits

Acqua & Sole calculated that the replacement of conventional fertilizer with digestate over a surface area of 5 000 ha would generate a maximum saved economic cost of about 2.3 million € y^{-1} (Table 5), but Acqua & Sole hasn't a direct savings from chemical fertilizers replacement. The implementation of N absorber will further reduce the N content in digestate, and as such not limit the digestate spreading on fields.

Table 5. Saved economic costs.

Conventional fertilizer	Cost € t^{-1} *	Quantity t y^{-1}	Total (€)
Urea 46% N	344	3 370	1 159 280
triple superphosphate 46% P_2O_5	369	2 520	929 880
Potash 60% K_2O	669	280	187 320
Total Saved Cost			**2 276 480**

** Source: CCIAA Modena, Average 2017*

This will allow distribution of a higher amount of digestate per hectare with benefits in terms of transport and disposal costs. On top of that, lowering NH_3 content in the digester will optimize the digestion process, by avoiding toxicity effects on methanogen microorganisms and increasing AS production.

Sustainability goals

Acqua & Sole is committed to reach the following targets:

- Increase soil quality and contribute to sequestration of carbon in soil
- Decrease greenhouse gas emissions
- Reduce NH_3, nitrate and nitrous oxide emissions
- Eliminate unpleasant odour to improve public acceptance and
- Promote nutrient recycling and this circular economy model in the region as an effective solution for waste management.

Monitoring data

A mass balance (Figure 4) was derived from the demonstration plant over a period of 280 days, from January 2018 to March 2019. During August and September the plant was not operational, however, it restarted in October and was again fully operational by January 2019. For this reason, the period August-December 2018 was not included in the monitoring activities. The aim was to evaluate the overall performance of Acqua & Sole demonstration plant, including the recovery efficiencies of the NH_3 stripping unit. In the NH_3 stripping unit, 10% of N was collected in the AS solution (with NH_4-N content of 74 g kg^{-1}). This translates into an NH_4-N recovery efficiency from digestate of about 22%.

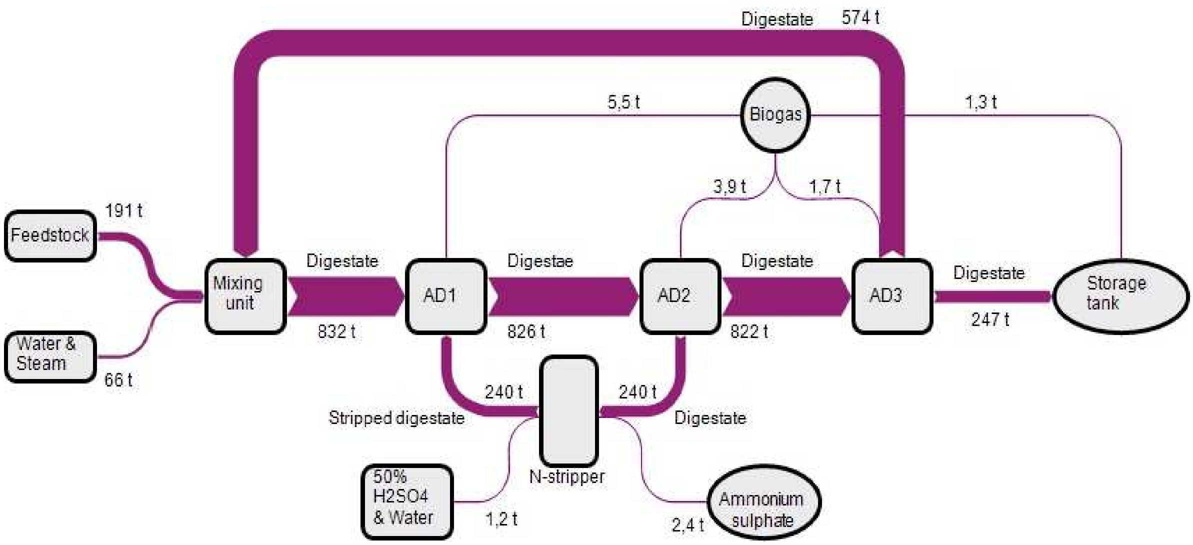

Figure 4. Mass flows at Acqua & Sole. Values are expressed in t d^{-1}.

RIKA Biofuels (Fridays, UK)

A short introduction to RIKA Biofuels

RIKA Biofuels (Table 1) develops large scale anaerobic digestion (AD) projects in Europe and is specialized in manure treatment from intensive livestock production.
RIKA Biofuels, partnered with DVO (supplier of the digester), has initiated the construction of the AD plant Fridays in the United Kingdom. Fridays will be operated with 100% poultry manure and a treatment capacity of at least 57.5 kt per year.

Table 1. Technical information of the biogas plant.

Characteristics	
Date of construction	2019
Size (MW_e)	2
Volume (m^3)	12 700
Digestion process	Mesophilic digestion

Drivers for Nutrient Recycling

To date, poultry manure is often incinerated because of the high organic matter content and low water content. The energy production during incineration is high, however, it causes valuable nitrogen (N) and carbon loss as N_2 and CO_2 in addition to greenhouse gas (GHG) emissions.
RIKA Biofuels wants to generate value from manure via AD and provide solutions to farmers whose manure is a liability to their business rather than an asset. The company realized that nutrient recovery could improve the efficiency of the AD by reducing the requirement for water to dilute high N-containing feedstocks (e.g. poultry manure). As a consequence, higher biogas yield and a more stable digestion process is achieved.
Fridays will demonstrate that chicken manure can be treated in a sustainable way while recycling N and phosphorus (P), reducing GHG emissions and reducing manure disposal costs.

Feedstocks

Every year the digestion plant will treat 57.5 kt of poultry manure (Table 2) diluted with more than 100 kt of recycled water coming from the nutrient recovery plant.

Table 2. Origin of Fridays feedstock.

Type	Origin	Mass
Manure	Poultry manure	57.5 kt

Biogas production

The installation will produce around 4.6 Mm^3 y^{-1} of biogas (Table 3).
600 m^3 h^{-1} of biogas will be upgraded to biomethane (350 m^3 h^{-1}) and injected in the local gas grid.
250 m^3 h^{-1} of biogas will be used in CHP engines to generate 499 kW of electricity and 523 kW of thermal energy.

Table 3. Yearly biogas production and average composition before purification.

Component	
CH_4 (%)	55
CO_2 (%)	44
H_2S (ppm)	500
O_2 (%)	0,7
Total biogas production (Mm^3)	4.6
Biogas per tonne of feedstock (m^3 t^{-1})	114

RIKA Biofuels (Fridays, UK)

Nutrient Recovery and Reuse (NRR) Technologies

The AD is a two-step, mesophilic mixed plug-flow system with a retention time around 20 days. The first step takes place in an acidification chamber, while the second occurs in a methanogenic chamber, allowing separation of bacteria for acid and methane formation. The waste flows through a channel as follows: as fresh manure enters one end, digestate is pushed out of the other end, continuously mixed with biogas circulation. The gradual increase of pH in the methanogenic chamber to 8.5 provides optimal conditions for subsequent ammonia (NH_3) stripping.

N is recovered as a valuable ammonium sulphate (AS, 38%) since during the process NH_3 is stripped by adding sulphuric acid (H_2SO_4, 90%). Up to 90% of P is recovered from digestate through a modified Dissolved Air Flotation step (mDAF) and subsequent squeezer. The investment for the AD plant and the N-stripping system amounts to 15 M€.

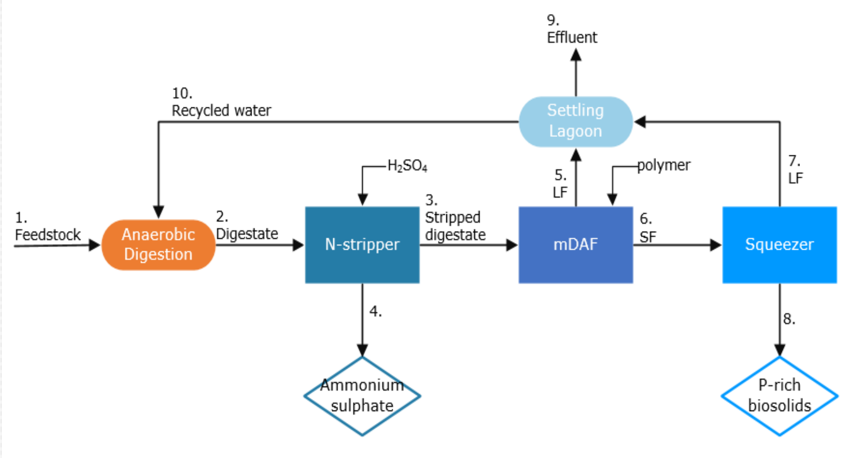

Figure 1. Flow scheme of RIKA Biofuels nutrient recovery system.

Status of construction

The reason for the delay in the construction of the biogas plant is that the Environmental Agency demanded detailed design at a very late stage in the planning application. RIKA Biofuels completed the design work and successfully attained planning permission for the project. However, in September 2016, changes in renewable energy policy occurred and Feed-In Tariff (RIKA's renewable subsidy) for projects with an output over 500 kW electricity (kW_e) has been effectively removed. Other potential uses of the gas (biomethane injection and liquid biomethane as a transport fuel) were explored, but the business case could not sustain without the CHP Feed-In Tariff.

Fortunately, RIKA Biofuels has another site under development at Fridays Eggs in Kent which will substitute Oaklands demonstration installation. This project is identical to Oaklands as it will rely on DVO technology to process at least 57.5 kt y^{-1} of poultry manure. This is a gas to grid project and as such does not rely on the Feed-in Tariff over 500 kW_e like Oaklands. The project has a planning permission, a grid connection and funding. After a delay of more than a year, the UK Government finally introduced new renewable heat tariffs in May 2018 for which RIKA applied. Subsequently, construction of the Fridays project started in December 2018 with the commissioning targeted to take place in November 2019.

RIKA Biofuels (Fridays, UK)

Products and market

Pathogen reduction by 90-99% of faecal coliforms and streptococcus will be ensured by the mixed plug-flow digester. The solids obtained with 20% of dry matter (DM) will be applied on local agricultural lands. By mixing biosolids with AS 38% solution, RIKA is planning to produce marketable NPK-fertilizers.
RIKA Biofuels is also exploring the option of crystallising AS solution. This can be achieved at a cost of about 60 € t^{-1} of crystal for which the market is thought to be in excess of 120 € t^{-1}.

Table 4. Expected composition of the recovered products.

	Digestate	Ammonium Sulphate	P-rich biosolids
Dry matter (g kg^{-1})	18	592	424
Organic matter (g kg^{-1})	7		402
N-total (g kg^{-1})	1.1	87	9.9
P-total (g kg^{-1})	0.24	0.22	2.4
K-total (g kg^{-1})	3.3	0.43	6.4

Economic benefits

The economic advantages of reusing recovered products are:
- Cost efficient production of biosolids and mineral organic fertilizers and
- Direct recycling of the final liquid fraction (e.g. feedstock dilution for AD) due to its low nutrient concentration.

Sustainability goals

RIKA Biofuels is committed to reach the following targets:
- Improving the sustainability of livestock farming through the production of renewable energy from the mono/digestion of manures and wastes from the agriculture sector and
- Achieving a GHG saving of at least 70% compared to fossil fuel alternative in RIKA's facilities for the production of renewable energy.

Benas-GNS, Ottersberg (GE)

A short introduction to Benas

The Benas demonstration plant is located in North Germany, near Bremen (Figure 1). The plant has a capacity of 174 kt y^{-1}, distributed over 4 digesters and 3 storage tanks (with a total volume 39 100 m^3, Table 1). Benas also includes an area of 3 500 hectares (ha) of arable land (1 000 ha near Ottersberg), with 35 employers and its own truck fleet.

Table 1. Technical information of the biogas plant.

Characteristics	
Date of construction	2006
Size (MW_e)	11.3
Volume (m^3)	39 100
Digestion process	Thermophilic digestion

Figure 1. Current NRR facility at Benas.

Drivers for nutrient recycling

Chicken manure is readily available in the region as a feedstock for biogas installations at a low gate fee. Nevertheless, due to ammonia (NH_3) inhibition of the anaerobic bacteria, it remains a difficult stream to digest and restrictions on nitrogen (N) application rates make hard to get rid of it after processing. This leads to high transportation cost over large distances. Benas, producing up to 400 t d^{-1} of digestate, has been hereby forced to search for a digestate treatment 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 the Ottersberg, which is fertilized with nutrients recovered at Benas installation. Trucks bring fertilizers to these agricultural fields and drive back to Ottersberg with crops that are used as feedstock input for the digester. Benas now already benefits from investments in nutrient recovery techniques: cost reduction on field application areas, less use of mineral fertilizer on their own lands, lower production costs due to the use of gypsum for recovering NH_3, income from selling the recovered biogas fibers.

Feedstocks

The co-digestion plant capacity is 174 kt organic substrate per year. In 2018, the co-digestion plant treated about 76.8 kt substrate, out of which 82% was crop material and 18% was manure (Table 2).

Table 2. Origin of Benas feedstock (2018).

Type	**Mass**
Corn silage	49.8 kt
Chicken manure	13.6 kt
Other solids	13.4 kt
Total	**76.8 kt**

Biogas production

The biogas produced every year is around 16.9 Mm^3 (Table 3). In terms of energy production, the plant generates 29 022 MWh_{th} y^{-1} of thermal energy, out of which 21% is consumed by the N-stripping unit and the remaining part is used for cooling stripping gas and biogas, heating the digesters, drying wood and corn silage and heating rooms in the building. The CHP engine also creates 23 828 MWh_e y^{-1} of electricity: less than 3% is necessary for the operation of the N-stripping unit, the rest is sent to the national grid.

Table 3. Yearly biogas production (2018) and average composition before purification.

Component	
CH_4 (%)	53
CO_2 (%)	46
H_2S (ppm)	83
O_2 (%)	0.1
Total biogas production (Mm^3)	16.9
Biogas per tonne of feedstock (m^3 t^{-1})	221

Gesellschaft für Nachhaltige Stoffnutzung mbH
GNS
Horizon 2020

Nutrient Recovery & Reuse (NRR) technology

After being stored in post-digesters, digestate undergoes a separation step, resulting in a liquid and solid fraction discharged on agricultural land. An internal recycle of digestate is used as a substrate for the FiberPlus plant for removing NH_3 (detailed description below). In this approach, NH_3 and carbon dioxide are brought into contact with gypsum to form ammonium sulphate (AS) and calcium carbonate (lime) (Figure 2).

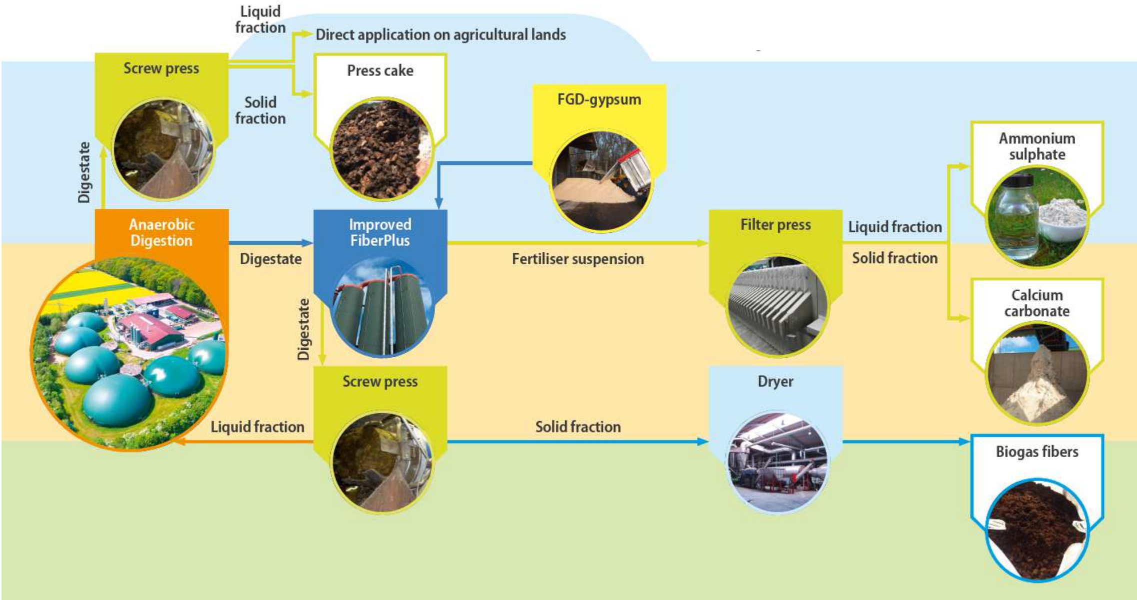

Figure 2. Current NRR facility at demonstration plant Benas.

Modified stripping process for N removal (FiberPlus process)

In 2003, GNS developed and patented the Modified Stripping Process in which NH_3 is stripped from digestate without any use of acids, bases or external stripping media (Table 4). The process requires the addition of Flue Gas Desulphurisation-gypsum (FGD-gypsum) to produce two marketable fertilizers: AS solution (22-26%) and solid lime (75% dry matter, DM). Moreover, the process does not require any external heat source and relies solely on the exhaust heat from the CHP engine, with an average consumption of 100 kWh per m^3 of digestate. The gypsum used for the process comes from FGD of coal power plants.

From 2007/2008 this type of stripper was installed at Benas and from 2011 the plant recycles N-depleted digestate back to the digester to increase its DM content. There are several advantages of the described system:

- The plant reaches a recovery rate of 80% of NH_3 contained in the digestate, which is approximately 200 t y^{-1};
- NH_3 inhibition is circumvented, increasing the biogas yield by 8%;
- Since 10/2016 the process has been further implemented with the FiberPlus System for the production of NH_3-free fibers suitable for different applications in the fiber and timber industries (i.e. fiberboard);
- Emissions and loss of N are reduced.

Table 4. Technical specification of the Modified Stripping Process.

Technical information	
Digestate input	5-25 m^3 h^{-1}
NH_3 input	3-5 g L^{-1}
DM input	5-12.5 %
Strip efficiency	70-85%
AS output	5-40 t d^{-1}
Lime output	1.5-14 t d^{-1}

SYSTEMIC
Circular solutions for biowaste

Benas-GNS, Ottersberg (GE)

Status of construction

In order to make the electricity production more flexible, Benas has completed the construction of an additional storage tank. Two additional CHPs have been installed and all digesters have been improved with new roofs.

Products and market

In 2018, the FiberPlus plant generated 592 t of solid calcium carbonate, 2 011 t of AS in solution and <1 000 t of biogas fibers. Product characteristics are given in Table 5.
The AS solution is recommended by GNS as a good fertilizer for several reasons:

- AS neutral pH is well tolerated by plants;
- AS concentration of 22-26% avoids evaporative crystallization, making it a suitable for direct application on crops and
- AS solution can be used for producing mineral fertilizer solutions or for upgrading manure or digestate low in N content.

Also, the use of lime has multiple advantages:

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

Table 5. Composition of the recovered products at Benas (average data January – April 2018).

	Digestate	Liquid fraction digestate	Solid fraction digestate	Calcium carbonate	Ammonium sulphate
Dry matter ($g\ kg^{-1}$)	119	100	258	695	224
Organic matter ($g\ kg^{-1}$)	82	65	222	29	0.48 (TOC)
N-total ($g\ kg^{-1}$)	8.2	7.4	8.7	15	46
P-total ($g\ kg^{-1}$)	1.7	1.5	2.2	0.16	<0.0037
K-total ($g\ kg^{-1}$)	1.2	6.6	5.6	0.42	0.0058

Economic benefits

GNS calculated that the replacement of conventional fertilizer with AS and lime would generate a saved economic cost around 300 000 € y^{-1} (Table 6). In addition, the sale of fibers is estimated around 82 000 € y^{-1}. Finally, storage and transport costs will decrease with the implementation of the N-stripper. This will reduce the N content in digestate, by-passing restrictions on N application rates.

Table 6. Saved economic costs.

Saved cost	€ y^{-1}
Use of AS solution	244 000
Use of calcium carbonate	63 000
Income from fibers	82 000
Total Saved Cost	**389 000**

Additional sources of income may be represented by:

- Digestate recycling after stripping and consequent higher biogas yield;
- Increase of chicken manure as substrate at lower prices (up to 50% of actual incoming N is contained in the dry chicken dung) and
- Efficient heat utilization.

Sustainability goals

Benas is committed to reach the following targets:

- Decrease GHG by lowering CO_2 emissions from digestate transportation and
- Reduce NH_3, nitrate and nitrous oxide emissions.

Monitoring data

Mass (Figure 3) and nutrient (Figure 4) balances were derived from the Benas over the period of four months, from January 2019 till April 2019. The aim was to evaluate the overall performance of Benas demonstration plants, and recovery efficiency of the NH_3 stripping unit. Results indicated that 31% of total-N contained in digestate processed in N-stripping unit was recovered as AS and 4.5% of total-N as calcium carbonate. This translates into an NH_4-N recovery efficiency from digestate of about 57% as AS and 7.8% as calcium carbonate.

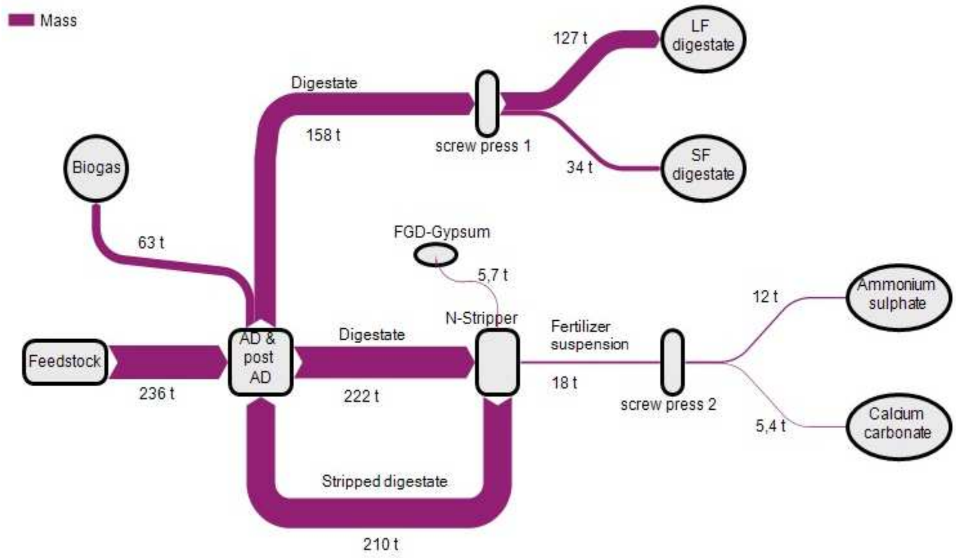

Figure 3. Mass flows at Benas. Values are expressed in t d-1.

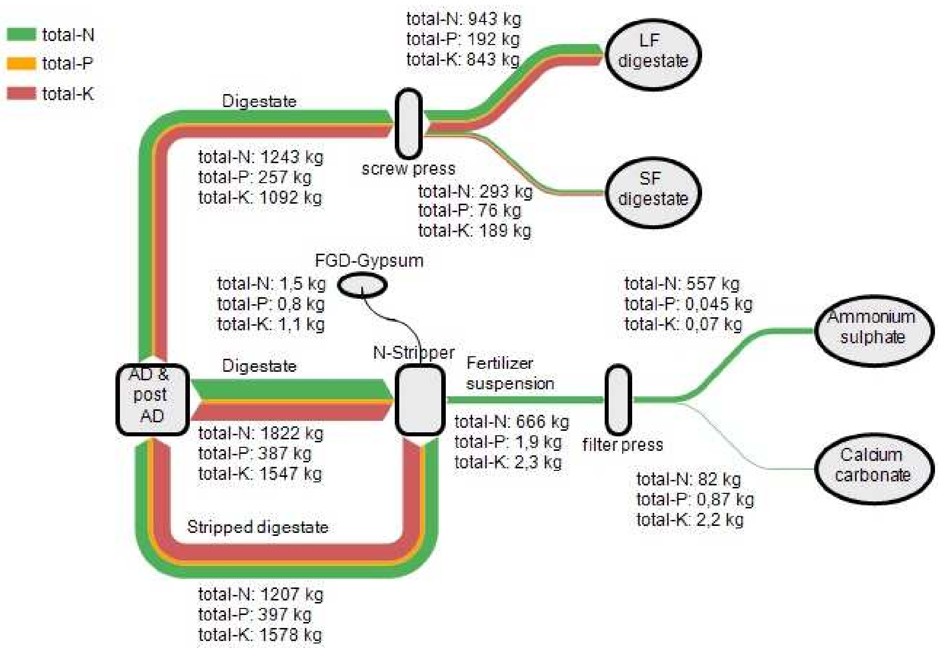

Figure 4. Nitrogen (total-N), phosphorus (total-P) and potassium (total-K) flows at Benas. Values are expressed in kg d-1.