Factsheet
SYSTEMIC demonstration plant

Acqua & Sole (Vellezzo Bellini, Italy)

A short introduction to Acqua & Sole

The biogas plant of Acqua & Sole (Figure 1) is located in Vellezzo Bellini (Northern Italy), in an area dedicated to cereal cultivation, mainly rice. This SYSTEMIC demonstration plant focusses on nutrient recycling, specifically development of equipment for digestate application to agricultural land (direct injection into the soil). This equipment is developed in collaboration with local farmers.

Table 1. Technical information of the biogas plant.

Characteristics	
Year of construction	2016
Maximum power output	1.6 (MW_e)
Digester volume	13 500 (m^3)
Digestion type	Thermophilic digestion

The aim for development of this equipment was to improve fertilisation and reduce ammonia (NH_3) and odour emissions. In addition to the production of a soil improver (digestate), the plant produces ammonium sulphate solution from recovered ammoniacal nitrogen (NH_4-N) by N-stripping of the digestate during anaerobic digestion (AD). This ammonium sulphate solution is used as N fertiliser. For the recovery and reuse of nutrients, Acqua & Sole has the ambition of improving the soil fertility of an area of 5,000 hectares without using any synthetic fertilisers. Acqua & Sole also wants to deliver recovered nutrients to surrounding farms.

Drivers for nutrient recycling

Degradation of N-rich digester feedstock leads to the formation of NH_3 which can have an inhibiting effect on anaerobic methanogenic microorganisms when toxic NH_3 levels are reached. Stripping of NH_3 and its subsequent recovery as ammonium sulphate solution is a great opportunity to prevent inhibition of the AD process. Furthermore, the low carbon contents of soils is an issue in Italy and the utilisation of soil improvers (i.e. digestate) is a valuable means to tackle this. However, N application rate limits for agricultural land limit the use of organic materials, making it necessary to find solutions to lower the N content of the produced digestate.

Figure 1. Aerial photo of the demonstration plant Acqua & Sole.

Feedstocks

The plant's co-digestion capacity is 120 kilotonnes (kt) organic feedstock per year. In 2020, about 88 kt of feedstock were digested of which roughly 84% was sewage sludge and roughly 16% was digestate from anaerobic treatment of source-segregated domestic food waste (SSFW) and agro-food waste (Table 2). The plant can digest animal manure, expired food, organic wastes, sewage sludge and agro-food industry waste.

Table 2. Origin of Acqua & Sole's digester feedstock (2020).

Type	Origin	Mass (kt)
Sewage sludge	Wastewater treatment plants	74
Co-substrates	Digestate from anaerobic treatment of source-segregated domestic food waste	4.5
	Agro-food waste	9.0
Total		**87.5**

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Biogas production

AD is performed in three consecutive digesters with a volume of 4,500 m^3 each. The produced biogas (Table 3) is converted into electrical anergy and thermal energy by a Combined Heat and Power (CHP) installation. From March 2020 onwards, part of the biogas is also fed to a back-up biogas boiler to meet the plant's heat demand, thereby avoiding the use of natural gas.

Table 3. Biogas production and average biogas composition before purification for the year 2020.

Parameter	Amount
CH_4 (% v/v)	60–67
CO_2 (% v/v)	32–36
H_2S (ppm)	<10
O_2 (% v/v)	<1
Total biogas production (Nm^3)	3.3 Mio
Biogas per tonne of feedstock ($Nm^3\ t^{-1}$)	38

Digestate characteristics

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

Figure 2. Digestate injection application on agricultural land.

Nutrient Recovery and Reuse (NRR) process

From April 2016 onwards, the plant has operated as follows (Figure 3):

- Feedstock (organic waste) is collected in basins located in a closed building to prevent the release of odour. A biofilter placed on the roof of the building purifies the exhausted air;
- The organic waste is then heated and mixed with digestate from the third digester;
- The mixed feedstock then undergoes thermophilic AD (minimum retention time of 20 days at a temperature of 55 °C) which ensures hygienisation of the ingoing sewage sludge;
- The system of digesters is equipped with a side-stream N-stripper, in which NH_3 is stripped from the stripping agent, biogas. This is done by leading biogas through 50% sulphuric acid resulting in an ammonium sulphate solution.
- For the previous absorption unit biogas was used as stripping agent. For the new N-scrubber, biogas has been replaced by air. Moreover, the novel N-absorber is made of the high-performance material Alloy 825, which allows higher process temperatures.
- The novel absorber design enables a higher gas flow rate, thereby increasing the recovery of NH_4-N from the digestate entering the N-stripper to up to 35%. With the previous absorption unit an NH_4-N recovery of just about 20% was achieved.
- Both the digestate and the ammonium sulphate solution are stored in close tanks.

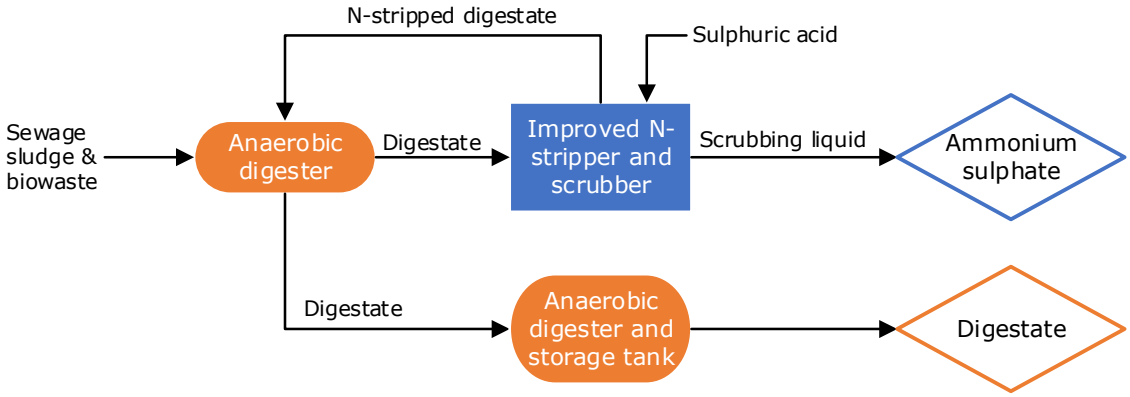

Figure 3. Simplified process flow diagram of Acqua & Sole's current nutrient recovery and reuse system..

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Status of construction

Construction of the novel N-absorber started in March 2019 and was completed at the end of 2019. For the start up of the new absorption unit the existing unit had to be switched of. This transitional period had to be as short as possible to avoid NH_3 inhibition of the digesters and took place in January 2020. Currently, the whole system is finalised and fully operational.

Products and market

The plant's co-digestion capacity is 120 kt organic feedstock per year. This feedstock is mixed with water and processed into at maximum 192 kt of N-stripped digestate per year. The composition of the produced end products is given in Table 4.

Acqua & Sole estimated that the use of N-stripped digestate replaces the following amounts of synthetic fertilisers per year: 1550 t N, 1160 t P_2O_5 and 170 t K_2O.

Table 4. Composition of the produced end products at Acqua & Sole (October 2020 – April 2021).

	N-stripped digestate	Ammonium sulphate solution
Dry matter (g kg^{-1})	106	360
Organic matter (g kg^{-1})	63	-
Total N (g kg^{-1})	8.0	75
Total P (g kg^{-1})	3.4	0.012
Total K (g kg^{-1})	0.59	0.017
Total S (g kg^{-1})	1.1	85

Economic benefits

There are no revenues to Acqua & Sole from the N-stripped digestate. Acqua & Sole however calculated that the replacement of conventional fertiliser with N-stripped digestate for 5,000 hectares agricultural land saves them about €2.3 million on conventional fertilisers per year (Table 5). The implemented novel N-absorber further reduces the N content of the N-stripped digestate. Therefore, even more of it can be applied per hectare on their own fields.

Table 5. Saved costs by application of N-stripped digestate.

Conventional fertiliser	Price (€ t^{-1})*	Quantity (t y^{-1})	Total costs (€)
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 costs			**2 276 480**

** Source: CCIAA Modena, average for the year 2017.*

This results in lower costs for transport and disposal. The further reduced NH_3 concentration in the digesters optimises the digestion process, by avoiding NH_3 inhibition of the microorganisms. Also, it increases the production of ammonium sulphate solution.

Sustainability goals

Acqua & Sole is committed to reaching the following targets:

- Closing nutrient cycles through the use of fertilisers produced from sewage sludge and biowaste;
- Showcasing that fertilisers produced from sewage sludge and biowaste are agronomically effective and environmentally friendly;
- Increasing soil quality, via carbon sequestration, due to the field application of digestate instead of conventional fertilisers;
- Reducing emissions of NH_3 and N_2O during field application of digestate;
- Reducing emissions of unpleasant odours during field application of digestate to improve public acceptance for their end products.
- Production of a highly stabile digestate and its field application via injection to improve its public acceptance. This is possible due to the absence of unpleasant odours during application.

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Monitoring data: total mass and nutrient mass flows

Total mass (Figure 4) and nutrient mass (Figure 5) flows were calculated for the plant for the period October 2020 – April 2021, 189 days in total. The calculated total amount of total N in the end products was 14% larger than the amount of total N in the feedstock, making calculation of the NH_4-N recovery efficiency difficult. A recent other study showed that the novel scrubber of Aqua&Sole can achieve NH_4-N recovery efficiencies of up to 35% (Di Capua *et al.*, 2021) relative to N-NH_4 in the feed of the stripper. As the stripper is operated on a side stream of the AD plant, overall N separation efficiency was lower (about 8% as compared to TN) which is sufficient to control N-NH_4 levels in the digester.

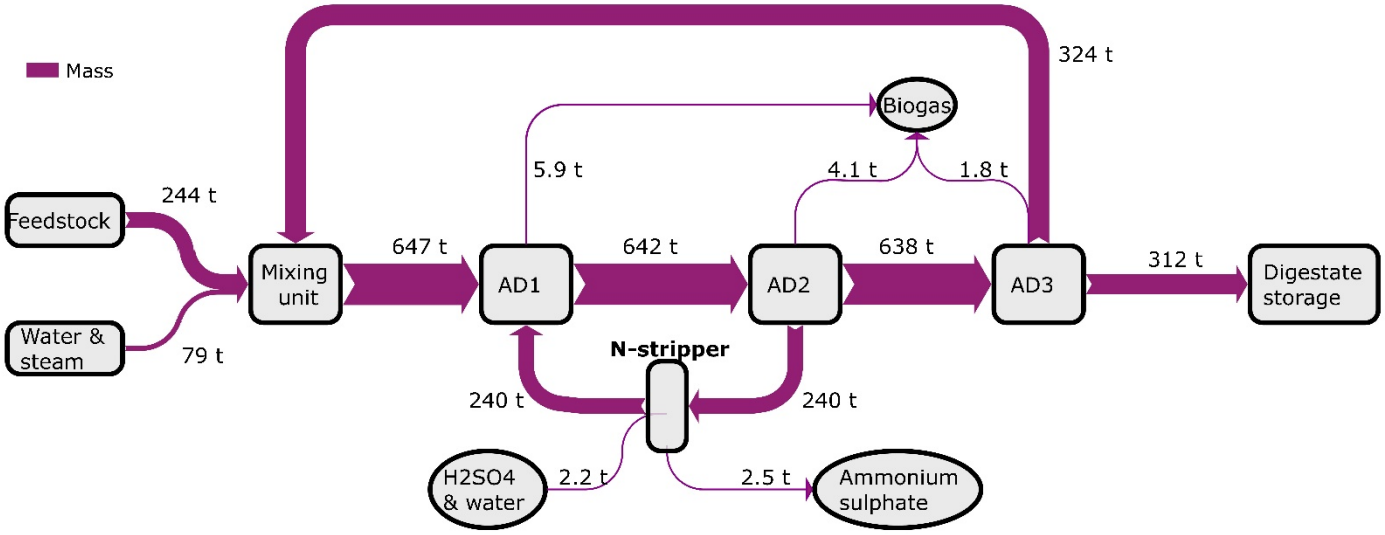

Figure 4. Total mass flows of the nutrient recovery and reuse system at Acqua & Sole in tonnes (t) per day.

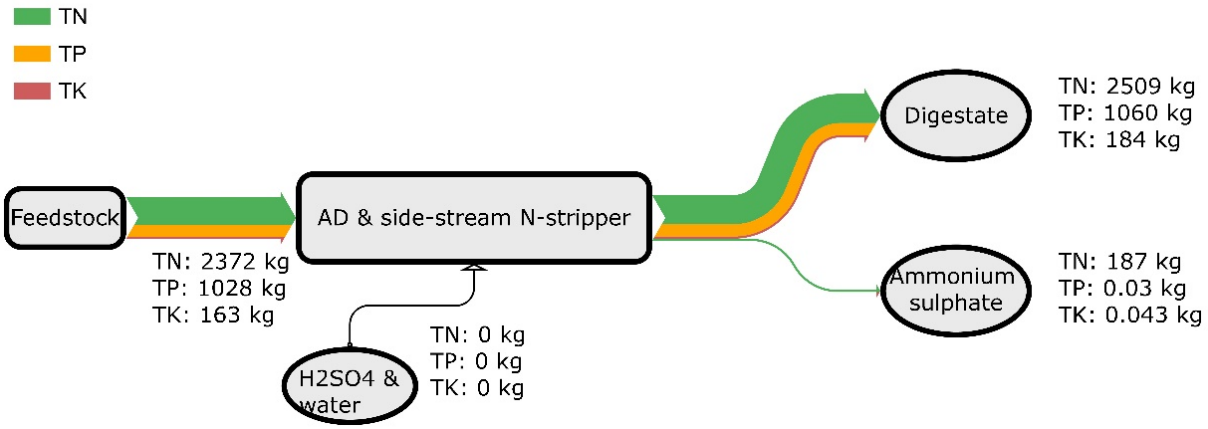

Figure 5. Total nitrogen (TN), total phosphorus (TP) and total potassium (TK) mass flows of the nutrient recovery and reuse system at Acqua & Sole in kilogram (kg) per day.

Di Capua, F., Adani, F., Pirozzi, F., Esposito, G., & Giordano, A. (2021). Air side-stream ammonia stripping in a thin film evaporator coupled to high-solid anaerobic digestion of sewage sludge: Process performance and interactions. Journal of Environmental Management, 295, 113075.

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Monitoring data: energy balance

Over the period October 2020 – April 2021 the plant generated 5,348 MWh of thermal energy, of which 5,103 MWh from biogas in the CHP installation. The remaining 245 MWh of thermal energy were produced from natural gas in the back-up boiler. This was needed as the biogas boiler, which is normally used, was not in operation for one month due to a technical issue. The CHP installation also generated 3,820 MWh of electricity, of which about 4% was consumed by the N-stripper (Figure 6).

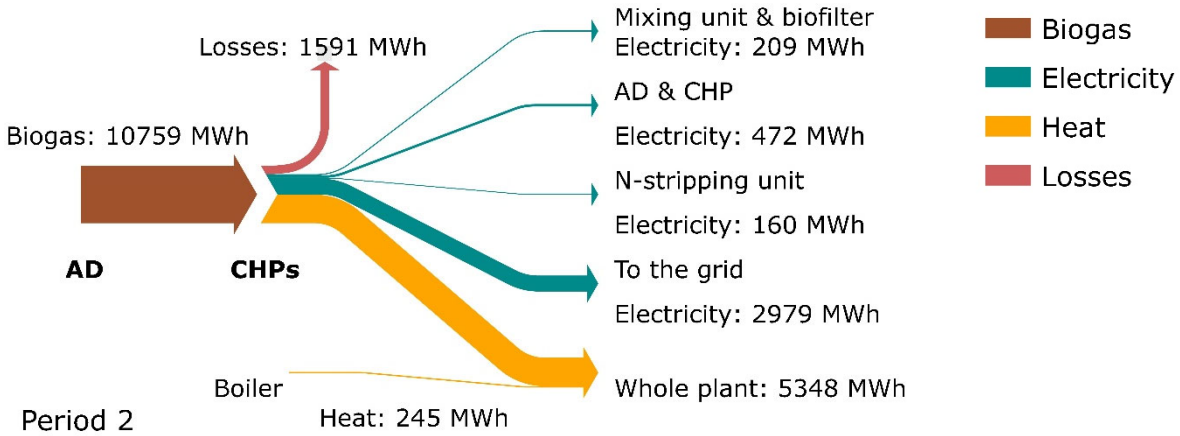

Figure 6. Energy balance of the anaerobic digestion (AD) and nutrient recovery and reuse system at Acqua & Sole for the period October 2020 – April 2021. CHPs: electrical and thermal energy generated by the CHPs includes thermal energy generated by the biogas boiler. Boiler: back-up boiler on natural gas.

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 Acqua & Sole's plant.

KPI	
EBIT margin	16%
EBITA margin	41%
Substrate productivity	€57 / tonne feedstock
Biogas productivity	€0.34 / Nm^3 biogas
Digestate productivity	€-4.6 / tonne feedstock

The plant has an average substrate financial productivity compared to the other SYSTEMIC demonstration plants. Even though the produced electricity is sold at market price, without any targeted support schemes, the plant's biogas financial productivity is still average compared to the other SYSTEMIC demonstration plants.

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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