IMPLEMENTING NUTRIENT RECOVERY FROM MANURE/DIGESTATE

(WPT1_Activity 2_Deliverable 2.2)

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Authors: Anne Adriaens[1], Imke Harms[2], Romke Postma[2], Amrita Saju[1], Ivona Sigurnjak[1], Erik Meers[1]

[1]Department of Green Chemistry and Technology, Faculty of Bioscience Engineering, Ghent University, Coupure Links 653, 9000 Ghent, Belgium
[2]Nutrient Management Institute, Nieuwe Kanaal 7C, 6709 PA Wageningen, the Netherlands

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Abbreviations

AD : Anaerobic digestion

$Ca(OH)_2$: Calcium hydroxide

CaO : Calcium oxide

CHP : Combined heat and power

CMC : Component material category

CO_2 : Carbon dioxide

DAF : Dissolved Air Flotation

HCl : Hydrochloric acid

HNO_3 : Nitric acid

H_2SO_4 : Sulphuric acid

K : Potassium

K_2O : Potassium oxide

LCA : Life cycle analysis

LF : Liquid fraction

MgO : Magnesium oxide

$Mg(OH)_2$: Magnesium hydroxide

N : Nitrogen

Na_2O : Sodium oxide

NaOH : Sodium hydroxide

NH_3 : Ammonia

NH_4NO_3 : Ammonium nitrate

$(NH_4)_2SO_4$: Ammonium sulphate

NRT : Nutrient recovery technologies

OM : Organic matter

P : Phosphorus

PLA : Poultry litter ash

P_2O_5 : Phosphorus (V) oxide

RENURE : Recovered nitrogen from manure

RO : Reverse osmosis

SF : Solid fraction

SME : Small and medium-sized enterprise

SO_2 : Sulphur dioxide

SO_3 : Sulfur trioxide

TRL : Technology readiness level

1. Introduction

Europe demands critical attention towards the inappropriate management of agricultural nutrients. One of the key steps to ensure the environmental security of the European Union (EU) is to close the nutrient loop and thus warrant the efficient use of agricultural nutrients. The transformation of Europe to a more circular economy can be brought by recovery and reuse of nutrients from biomass streams like animal manure, sewage sludge and food waste which can contribute greatly towards improving the efficiency of nutrient management. Different nutrient recovery technologies (NRTs) are needed to enable the recovery of nutrients from biomass streams. Currently there are several of them available in the market. Each technology, however, deals with its own issues related to implementation and/or operation. Most of these issues might be seen as constraints towards the further uptake of technology in the market, thus, limiting nutrient recovery on the European level.

ReNu2Farm is an Interreg North West Europe (NWE) project that focusses on nutrient recycling and upscaling from pilot level to farms and fields. Its priority specific objective is to optimise the reuse of material and natural resources in NWE. One of the tasks of the project is to provide an overview of production and implementation aspects with due attention for constraints and bottlenecks observed when trying to implement their existing technologies in practice. This report focuses specifically on implementation of NRTs from manure/digestate at 6 processing sites: Detricon, AMPower, Arbio (Flanders, Belgium), Attero, BMC Moerdijk and Groot Zevert Vergisting (the Netherlands). Only Flemish and Dutch companies were interviewed because the region of Flanders and the Netherlands are known for nutrient surplus and hence fast development of NRTs. In the following chapters, the implemented NRTs will be described with respect to its working principle, current scale of operations (technology readiness level (TRL)) and fertiliser generation. Finally, past, current and future expected constraints will be stated by the technology user, with specific focus on logistics, production, legal and market bottlenecks.

The consortium of ReNu2Farm project would like to thank owners/managers of Detricon, AMPower, Arbio (Flanders, Belgium), Attero, BMC Moerdijk and Groot Zevert Vergisting (the Netherlands) for their valuable input.

2. Detricon (Belgium): Ammonia stripper-scrubber

2.1. Brief history and activities of the company

The Detricon installation is situated at the IVACO pig husbandry site, located in a rural zone of Flanders (Gistel) where agriculture is one of the main economic activities. The intensification of pig farming has led to increasing quantities of (liquid) manure, while environmental legislation limits its local use as a fertiliser. Hence, the decision was made at IVACO to invest in a manure treatment facility. In the first stage, the investment in a centrifuge, a composting hall and a biological treatment was made with a focus on the valorisation of the solid fraction (SF) of animal manure by export, and on the reduction of the environmental impact of the liquid fraction (LF) of animal manure by a nitrification-denitrification treatment. The addition of an anaerobic digestion (AD) installation and an ammonia (NH_3) stripper-scrubber pilot (Figure 1), implements the next step towards a closed-loop farming by increasing energy and nutrient recovery. Hereinafter, the main focus is on the implementation of the NH_3 stripper-scrubber pilot plant that is operated by Detricon.

Figure 1. The Detricon ammonia stripping-scrubbing plant at the IVACO site

2.2. Description of technology

The raw manure and the digestate from the AD are first treated in the centrifuge. The phosphorus (P) rich SF goes to composting, whereas part of the nitrogen (N) and potassium (K) rich liquid fraction is sent to the NH_3 stripper. In the NH_3 stripper, a counter-flow air current captures the NH_3. In the subsequent absorber part (i.e.

scrubber), the NH_3-rich gas is washed with an aqueous acid solution (contains nitric acid (HNO_3)) which results in a liquid with about 10 % ammonium nitrate (NH_4NO_3). By treating the LF in an NH_3 scrubber unit using HNO_3 instead of the commonly used sulphuric acid (H_2SO_4), a liquid fertiliser with a higher N-content is produced. The pilot plant runs with a capacity of 15 000 – 20 000 tonnes y^{-1} with a 50 % NH_3 reduction without addition of a pH raising agent like sodium hydroxide (NaOH). The required energy is generated on site in the combined heat and power (CHP) plant from the AD and by solar panels. Both the flow rate and the reduction capacity depend on the process parameters (i.e. air flow, pH of the system, packing density of the scrubber, temperature, dosage of a base…). Different tests are run to investigate the impact of process parameters, the energy consumption and the overall environmental and economic impact.

The plant currently has a TRL of 7 : system prototype demonstration in operational environment. Upscaling is foreseen within the next year(s). In order to increase the TRL, additional testing is needed, both on the producer-side and on the user-side. The following research activities are on-going :

- Producer-side: Additional test runs will enable Detricon to optimise the process parameters and guarantee the stable performance of the installation.
- User-side: Field tests with different crops are currently on-going to demonstrate the quality of this recovered fertiliser and the equivalence with 'conventional' fertilisers. It will also help to inform farmers and induce its use.

The implemented technology is not yet taken up sufficiently by the market for the following reasons:

- The Joint Research Centre of the European Commission made a proposal (SAFEMANURE project) for harmonised criteria that could allow fertilisers, partially or entirely derived from manure, to be used in nitrate vulnerable zones following the same provisions applied to N containing chemical fertilisers in the Nitrates Directive (91/676/EEC), while ensuring adequate agronomic benefits. These fertilisers are referred to as REcovered Nitrogen from manURE (RENURE). However, as long as the legal framework for these criteria has not been established, the NH_4NO_3 fertiliser (as produced by Detricon) is still considered to be an animal derived fertiliser and thus subject to the max 170 kg N ha^{-1} y^{-1} from the Nitrates Directive, which hampers both commercialisation of the product and the roll-out of the technology.
- Air scrubbing systems are commonly used in pig husbandry to clean the air by removing the NH_3. These systems usually scrub NH_3 with an aqueous H_2SO_4 solution thus producing ammonium sulfate ($(NH_4)_2SO_4$).

By using an aqueous HNO_3 solution, Detricon produces NH_4NO_3 which has a higher N-content. Based on molecular mass, the N-content increases from 21 to 35 %.

2.3. Generated product(s) from the implemented technology

The Detricon site produces NH_4NO_3 (Figure 2), which is a liquid N-fertiliser with a total N of approximately 10 % and a pH of 6-7. The pilot plant runs with a capacity of 15 000 – 20 000 tonnes y^{-1} and produces 600 tonnes y^{-1} of NH_4NO_3 (10 % N_{tot}). The product was certified as a fertiliser and/or soil improver in line with the Flemish legislation regarding end-of-waste. As the NH_4NO_3 is produced by a recovery process, this certificate is a legal requirement for commercialisation of the NH_4NO_3 as a fertiliser. However, for successful commercialisation, an additional certification, namely the acceptance as RENURE is needed.

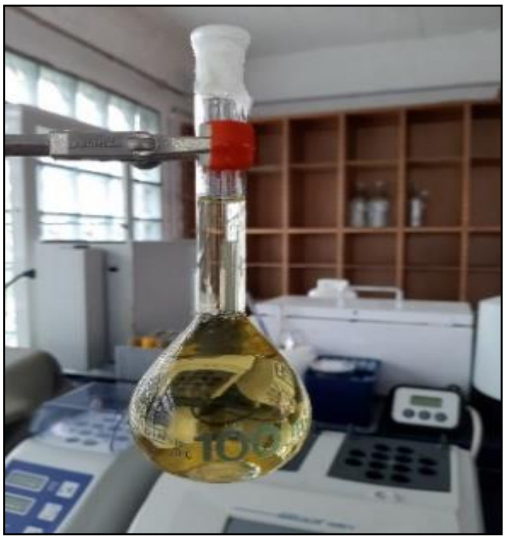

Figure 2. Ammonium nitrate produced by the Detricon stripping-scrubbing process

2.4. Implementation constraints

- Technological constraints

For the NH_3 scrubbing, a strong acid (either HNO_3 or H_2SO_4) is required. The storage (and all associated handling such as filling up, pumping, …) of a strong acid requires safety measures and entails certain risks.

Although the stripping-scrubbing technology is a proven technology, the start-up of a tailor-made installation always involves some teething problems. The problems encountered in this installation were related to the properties of the input material (a high organic loaded LF). The suspended solids of the material can cause clogging of the packing material in the scrubber. During the air stripping, foaming can occur due to the organic content that acts as a surfactant.

- Production and logistical constraints

The efficiency of the system depends on the pH of the LF and if its pH has to be increased, this is an extra cost.

The legal framework for RENURE fertilisers such as the NH_4NO_3 from Detricon criteria has not yet been established. This means that the NH_4NO_3 fertiliser as produced by Detricon is still subject to the max 170 kg N ha^{-1} y^{-1} from the Nitrates Directive. Farmers normally use that quota by spreading raw manure of their own animal husbandry activities, supplemented with synthetic fertilisers to meet the nutrient requirements of the crops. For a successful commercialisation of the NH_4NO_3, it thus has to be marketed as a substitute for synthetic fertilisers. This requires the legal certification as an end-of-manure status, however, this legislation is not yet in place.

- Product-related constraints

Commercially, the NH_4NO_3, from Detricon has a competitive disadvantage compared to the common synthetic N-fertilisers because of the lower N-content. At the moment, the composition of the product is mainly determined by the production process and it will be difficult to attain N-concentrations similar to the synthetic N-fertilisers. At the same time, the product will only be used and bought by farmers if composition, nutrient ratio, etc., correspond to the farmers' requirements. If the product cannot meet the desired characteristics, it could be used as N-source in tailor made fertilisers, although, this pathway still needs further investigation.

Like all ammonium N rich fertilisers, an adequate fertilising technique is required to reduce the risk of volatilisation. Furthermore, the nitrate in the product increases the risk of leaching. That is why the application has to be done carefully, using doses and timing attuned to the plant requirements.

- Other encountered constraints

About 10 years ago, investments in the AD sector in Flanders were substantially reduced after a wave of bankruptcies. Therefore, it is still hard to find funding for projects developing and implementing nutrient recovery. However, those investments are exactly indispensable to improve the cost competitiveness of the AD installations by valorising the digestate. Investments in installations for nutrient recovery are generally paid by private investors, which is a constraint. The Detricon installation was paid by the owner's capital. Personnel costs for research, development and market implementation were partly paid by project subsidies.

For more information on Detricon's activities, feel free to visit:

https://detricon.eu/

3. AM-Power (Belgium) : Evaporation of liquid fraction of digestate

3.1. Brief history and activities of the company

AM-Power is one of Belgium's largest AD plant (Figure 3). AM-Power started its activities in 2011 and is located in the western part of Flanders (Pittem), a region with a high density of arable cropping and intensive pig farming. Both activities generate considerable amounts of residues, such as organic waste streams (starch, potato peels, sludge) from the agricultural industry and pig slurries. The plant aims to valorise both, the energy and the nutrients of these residues. AM-Power is a small and medium sized enterprise (SME) and currently employs 10 persons.

Figure 3. Aerial view of AM-Power plant

3.2. Description of technology

The AD processes about 180 000 tonnes y^{-1} of organic waste, including about 20 % of manure. The thermophilic AD is spread over four digesters and one post-digester. The produced biogas is converted to thermal and electrical energy in a CHP. The site has a yearly production of 7.5 MWe and all thermal energy is re-used on site during the conversion of the digestate into nutrients, namely the heating of the AD, the dryer and the evaporator (Figure 4).

Once polymers are added, the digestate is pumped to the centrifuge resulting in SF and LF. The SF of digestate is dried in a fluidised bed dryer and converted into a P- and C-rich biosolids that are exported. A two-phase air scrubber cleans the exhaust air from the dryer : a H_2SO_4 stripping unit, followed by a biofilter, cleans the air. This substantially reduces the odour nuisance to the environment. The LF of digestate undergoes the following processing:

- Lowering of the pH to about 6 to convert the volatile NH_3 into NH_4-salts (i.e. ammonium sulphate ($(NH_4)_2SO_4$))
- Evaporation of the LF to produce a nutrient-rich concentrate.
- Additional purification of the distillate in the Reversed Osmosis (RO) installation.

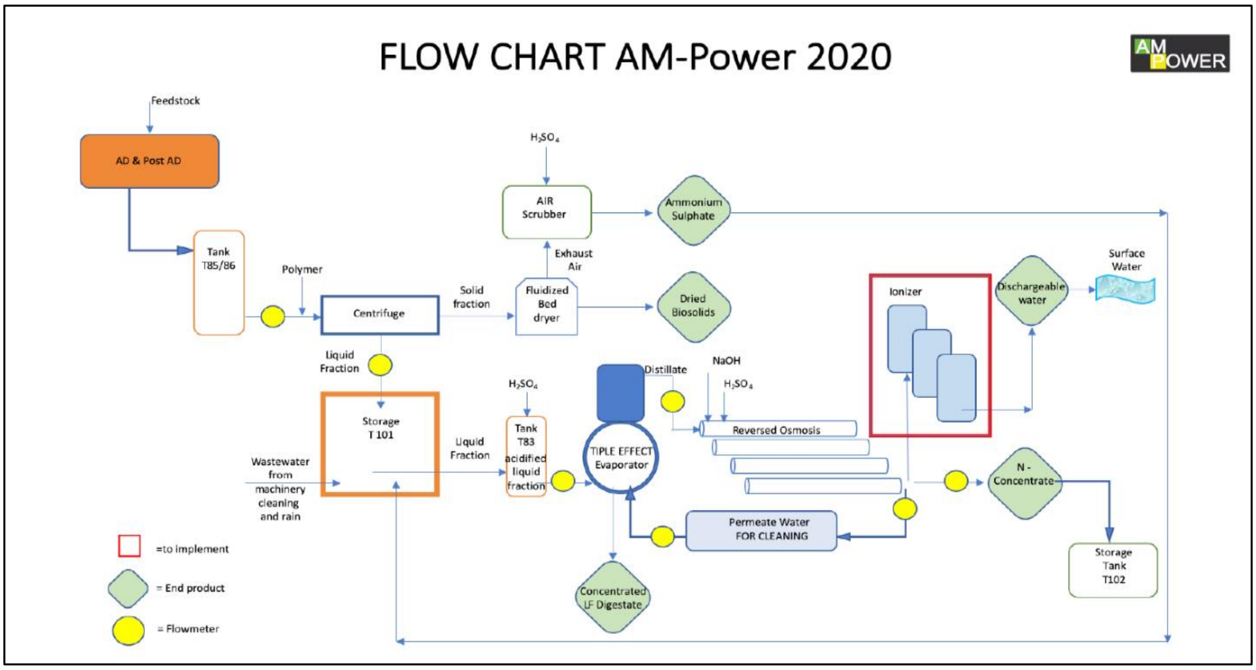

Figure 4. Flowchart AM-Power

The plant operates at TRL 9 : system proven and running in operational environment. The evaporator was recently added to the installation in order to optimise the system and improve the nutrient recovery (Figure 5). The implementation of the evaporator has the following benefits:

- Overall optimisation of the process, especially the centrifuge system, since both the recirculation load towards the centrifuge as well as the consumption of polymers are decreased.
- Improved nutrient recovery.
    - Before this investment, the LF after centrifuge was directly sent to the RO. This resulted in a split into a water fraction (50 %) and a concentrate (50 %) with only 5 % dry matter (DM). This concentrate was used as a NK fertiliser on grasslands. The low concentration incurs high transport costs if it has to be moved over significant distance, therefore, the use of the concentrate was limited to the surrounding area of the plant. Moreover, as the use of the fertiliser is forbidden during several months in the autumn-winter period, a substantial storage capacity was needed.
    - Thanks to the evaporator, nutrients are more efficiently accumulated in the concentrate. This also results in a cleaner distillate and a lower load to the RO. This concentrate is currently stored during the start-up phase of the new installation. In the near future, it will be added to the P and C-rich biosolids. This will increase the N and K-content of the biosolids, thus improving the N-P-K ratio of the fertiliser.

Figure 5. Evaporator with vertical distillation column

At the moment, the purified water is stored. Once the analytical results are available, it will be discharged into surface water. As a next step towards valorisation, the company is investigating the option to recycle this water to agriculture.

3.3. Generated product(s) from the implemented technology

As the final end-products, the AM-Power site produces P and C rich biosolids and NPK-rich concentrate (Table 1).

Table 1. Products derived from nutrient processing at AM-Power and their brief characteristics

Name of the product	Biosolids	Concentrate
Brief description of the product	P, C-rich fertiliser	- N, P, K-rich fertiliser
Composition	• DM (%) : 80-90 • OM (%) : 43 • N_{total} (g/kg) : 27 • P_2O_5 (g/kg) : 50 • K_2O (g/kg) : 12	• DM (%) : 14-16 • OM (%) : 50-59 • N_{total} (g/kg) : 4.1-9.2 • P_2O_5 (g/kg) : 1.9-3.3 • K_2O (g/kg) : 10-13
Yearly production	8000 t	15 - 20 000 t
Current utilisation of the product and market	Exported as a fertiliser	Exported as a fertiliser

DM : Dry matter; OM : Organic matter; P_2O_5 : Phosphorus (V) pentoxide ; K_2O : Potassium oxide.

3.4. Implementation constraints

- Technological constraints

The up-concentration of digestate is a challenging processing step - as the concentration increases, the viscosity increases which in turn enhances the risk of clogging and/or sticking. The choice of technology is thus of utmost importance to reduce system failure and maintenance. The technology of a falling film evaporator was not chosen because of the risk for clogging and associated maintenance costs. Instead, AM-Power invested in a system with panels whose surface is continuously cleaned by brushes.

The recuperation of nutrients from digestate requires a specific type of technology and the technology also has to be appropriate for the material processes. Since nutrient recovery is still at an early stage, the number of technology providers in the market is limited. Moreover, every project is tailor-made and requires good engineering skills.

- Production and logistical constraints

The installation and implementation of a new process requires a lot of testing and fine-tuning until the correct set-points and a stable product concentration are obtained. Thanks to the higher concentration of the concentrate, storage and transport volumes have decreased.

- Product-related constraints

Manure-derived fertilisers have to comply with legal requirements and certification procedure. As the composition of the biosolids changes by adding the concentrate, the effective marketing can only be started once the required paperwork is concluded.

In Flanders, the manure legislation (Manure Action Plan) strictly controls and restricts the use of fertilisers, especially manure and manure-derived fertilisers. Because of the high N and P concentration in the biosolids, the amount that can be applied locally is limited. This hinders commercialisation in Flanders.

- Other encountered constraints

Due to a number of bankruptcies in the period 2012-2014, all banks in the region of Flanders (Belgium) withdrew from investments in biogas installations and stopped granting loans for biogas installations and related manure treatment investments. In order to finance the investments, external capital had to be attracted.

For more information on AM-Power's activities, feel free to visit:

https://www.vlaco.be/vlaco-vzw/producten/am-power-bv

4. Arbio (Belgium): Reverse osmosis

4.1. Brief history and activities of the company

Tim Keysers and his wife, the owners of Arbio, both grew up on a farm. During his graduation project, Tim studied the AD process and the digestate treatment techniques and he was eager to implement NRT in his company.

Tim runs a mixed farm, with about 5000 fattening pigs, 500 sows and 110 ha arable land. The initial installation, built in 2012, consisted of an AD unit with a subsequent biological treatment (i.e. nitrification-denitrification) of the digestate (Figure 6). As the plant is surrounded by arable land, the effluent from the biological treatment, which still contained considerable concentrations of N and P, was used for fertigation.

Nitrification-denitrification converts the mineral ammonia and nitrate, valuable plant nutrients, into N_2 gas that is emitted into the atmosphere. N in the form of N_2 can only be converted to mineral N-fertilisers by the energy-intensive Haber-Bosch process. In order to keep these N-nutrients in the loop and close the N-circle, a new investment in reverse osmosis (RO) was planned.

Figure 6. Aerial view of Arbio plant

4.2. Description of technology

The technology implemented at Arbio is called NPirriK, can be summarised as follows. In the AD, about 80 – 90 000 tonnes y^{-1} of organic biological waste (40 000 tonnes y^{-1}) and animal manure (50 000 tonnes y^{-1}) are digested. The biogas fuels a CHP with a yearly production of 3.5 MWe. All heat is used locally during the digestion and the processing of the digestate, and 85 - 90 % of the electricity is fed into the grid. The digestate is pumped to a filter belt press (Figure 7) which produces a nutrient rich SF of digestate with 80 % DM and a LF of digestate. The substitution of the original centrifuge by a filter belt press led to multiple benefits:

- A higher separation efficiency, resulting in a higher P and C-content in the SF of digestate and a reduction of chemical oxygen demand (COD) in the LF of digestate, which facilitates the valorisation of the LF.
- A reduced use of polymers.

The LF of digestate undergoes a first purification in a decanter before being sent to the RO (Figure 8). In the RO, the LF of digestate is split into a concentrate (40 %) and an aqueous fraction (60 %). The concentrate is added to the SF of digestate, which increases the N-content of this fraction. As a final step, SF is sent to a belt dryer to increase DM up to 90 % and to a pellet press (Figure 9 and Figure 10). After these processing steps, the solid fertiliser is ready for export.

The aqueous fraction is used for irrigation on the surrounding arable lands. Both the total amount and the salinity have decreased in the aqueous fraction, compared to the former effluent of the biological treatment (i.e. nitrification-denitrification). The biology is still active for treatment of the suspended solids (limited volumes) of the decanter and the backwash waters.

The new process (filter belt press – RO – belt dryer) clearly closes the N-cycle, instead of being released as N_2 in the air, since the majority of the N is now recovered in the concentrate and added to the fertiliser pellets. In addition, a pellet with a higher N/P ratio is more in line with the nutrient requirements of most crops and therefore also a fertiliser with a higher quality (especially in regions with P saturated soil), which is reflected in a higher selling price. It is also an interesting product for Flemish agriculture and horticulture. As the RO only uses about one-third of the energy that would be needed by biological treatment, the new installation also saves energy.

Figure 7. Filter belt press

Figure 8. Reversed Osmosis

Figure 9. Pellet press

Figure 10. Pelletisers

The plant, in its current scale and set-up, has been operational for more than one year. It thus has a TRL of 9 : system proven and running in operational environment. Although the different process steps of the NPirriK system can be considered as common technologies, it is the combination of the different processes as well as the fact that it is used for treatment of animal manure that makes it novel and ground-breaking. This explains why the installation received the Ivan Tolpe award, a Flemish initiative but open to international applicants. This bi-annual award supports and highlights innovative techniques regarding manure treatment. The NPirriK system as such is not yet taken up sufficiently by the market.

4.3. Generated product(s) from the implemented technology

The main end-product produced at Arbio site are fertiliser pellets (Figure 11) with 90 % DM, 64 % organic matter (OM), 5.5 % N_{tot} and 2.6 % N_{min}, 2.8 % P_2O_5, 2.3 % K_2O. Yearly production of the product is 6 000 tonnes y^{-1}. The fertiliser pellets are currently exported to European countries with a high nutrient demand, such as France, Poland and Romania.

Figure 11. Arbio fertiliser pellets

4.4. Implementation constraints

- Technological constrains

The NPirriK system is a tailor-made system, consisting of different process steps. The system, especially the combination of techniques, is novel and no similar installations exist currently.

Technology providers are scarce and each provider has their specific technical expertise, which makes offers from the technology providers difficult to compare. Not all technologies can be supplied by a single provider. The different process steps have to be aligned (volume, concentration, ...). This requires intensive start-up testing and tuning. A learning curve of about 15 months was required for installation, automation, dosing, commercialisation of pellets, etc.

- Production and logistical constraints

The installation requires intensive maintenance. It has to be continuously monitored and supervised.

- Product-related constraints

Since the whole region of Flanders is classified as a nitrate vulnerable zone, the Flemish legislation dictates different measures to reduce the leaching and run-off of nutrients. It thereby incentivises the export of manure-based fertilisers. As a consequence, Flanders exports bio-based fertilisers while simultaneously importing and using synthetic fertilisers. The legal equivalence of both bio-based and synthetic fertilisers, as well as a wider acceptance by and higher demand from farmers is needed to counter this situation.

- Other encountered constraints

Except for the 100 000 € subsidy it received from a Flemish circular economy fund, the NPirriK system was completely funded with own capital.

For more information on Arbio's activities, feel free to visit:

https://www.vlaco.be/vlaco-vzw/producten/arbio-bv

5. Attero (the Netherlands): Anaerobic digestion and composting of bio-waste from households

5.1. Brief history and activities of the company

Attero started treating organic waste separated from mixed household waste in 1929 on their first location in Wijster in the North of the Netherlands. Since 1994, composting is only carried out for source-separated bio-waste and in 2008, Attero also started AD (Figure 12) followed by composting of the digestate to produce biogas for renewable electricity and green gas. Today, about one-third (600 k tonnes) of the collected household bio-waste volume is digested before composting. The business development was driven by Attero's ambition to produce the maximum amount of secondary resources and renewable energy from waste and made feasible by legislation and subsidy policies : municipalities pay Attero for bio-waste treatment and government subsidises green energy production.

Figure 12. Two - phase AD plant at the location in Venlo

Attero is currently treating bio-waste in seven different locations in the Netherlands : Moerdijk, Tilburg, Deurne, Venlo, Maastricht, Wilp and Wijster. The input material comprises of source-separated bio-waste from households but also green cuttings and catering waste as well as waste streams from the food industry. Four installations are equipped with AD to produce biogas. At two facilities the biogas is upgraded to green gas by removing impurities and carbon dioxide (CO_2). The quality of the green gas resembles natural gas and can be injected in the gas grid. Between 2011 and 2015, Attero increased its green gas production to 23 million m^3 which is about 23 % of the total green gas production in the Netherlands. In both Tilburg and Wijster, the installation is extended with other biogas producers, the biogas hub, to make the biogas upgrading installations profitable by sharing infrastructure after which green gas is fed into the gas network. As a by-product, CO_2 is produced and in one biogas upgrading plant, this is used in greenhouses.

For composting, different installations are in use, depending on the location : tunnel, large indoor halls and open-air composting. The installation in Venlo is equipped with a 2-phase digester which allows to recover valuable organic substrate material of a quality that can replace peat in potting soils. It needs to be specifically low in salt content as well as clean in terms of weed seeds, plant pathogens and impurities. Attero is the first producer internationally who is producing this substrate on a large scale.

Attero also runs one 'Biomass and Energy Centre' in Odilliapeel where steam is produced out of the woody fractions of bio-waste. The steam is used by a neighbouring potato convenience product industry to steam-peel potatoes. Besides source separated bio-waste from households, Attero also treats and recycles other types of waste collections like plastic waste, mineral waste and residual waste. The latter is incinerated with energy valorisation to produce heat and electricity. Plastics are cleaned and plastic pellets are sold which allow reproduction of packaging material. Besides, Attero also cleans polluted soil material.

5.2. Description of technology

Attero applies a combination of AD and composting to household bio-waste with several purposes:

- Transformation of bio-waste into a valuable organic substrate which can be returned to the soil in arable and horticultural agriculture or in landscaping, thereby closing the nutrient cycle.
- Energy production and upgradation to green gas.
- Valorisation of woody biomass to steam which is used by the food industry afterwards.

The recovery technology of Attero manages to recover nutrients but at the same time also to produce bioenergy. This is an innovation compared to common practices of landfilling or solely composting, of which the latter produces a valuable substrate but no bioenergy.

At the location in Venlo, a 2-phase digester operates in a following manner (Figure 12) : in the first step, fatty acids are extracted from the bio-waste, in a second step this enriched water is digested. As an in-between step, salts are washed out which makes the organic substrate a valuable peat-replacement for potting soil. Another future option for resource valorisation could be to recover the fatty acids as a separate substance to sell e.g. for bioplastic production. However, upgrading technology would need to be implemented and the market needs to be developed.

Household bio-waste is transformed into valuable soil amendments which can be applied to soil and thus return nutrients to food production. The digestion and composting process assures that weed seeds are suppressed. Further, sieving and cleaning steps are in place at Attero to guarantee good compost quality.

Currently, 700 000 tonnes of bio-waste are treated, producing 320 000 tonnes of compost and with digestion and gas upgradation, 18.4 million m^3 of green gas is produced yearly. Upscaling is limited since more bio-waste is unavailable, except when municipalities further increase the separate collection of bio-waste. AD including upgrading of biogas to green gas as well as composting are implemented at TRL 9 : system proven and running in operational environment. Biogas production received a boost with subsidies for green energy production in the period 2000 to 2010. This type of technology is widely applied in the sector of bio-waste treatment, at least in Central Europe.

5.3. Generated product(s) from the implemented technology

Attero is producing compost of different qualities, including a peat-replacement substrate (Figure 13). In total, 320 000 tonnes are produced yearly. A large fraction, about 60% is taken up by arable farming in the Netherlands as a soil amendment. These volumes are almost entirely certified as quality compost by the Dutch National certificate " Keurcompost" which allows in the highest quality class a maximum of impurities of only 0.05 %. Another 30 % of the produced volume is substrate to the potting soil sector.

Figure 13. Attero produces compost suitable as a peat-replacement for potting soils

5.4. Implementation constraints

- Production and logistical constraints

The fraction of inorganic impurities in the bio-waste collected from households has increased by a factor of four over the past twenty years. One reason is that the compost sector has not monitored the quality well enough in the past and therefore has not demanded a high-quality of input material. Secondly, municipalities have had a drive to minimise the amount of residual waste while paying somewhat less attention to the quality of the source-separated streams. Also, with different types of packaging, bio- and non-biodegradable, consumers are increasingly confused about which packaging can go into the compost bin and which cannot.

For the future, Attero is preparing to become more active in treating road and canal- side verge grass cuttings. In the Netherlands, with its many canals, verge grass represents a large resource for organic matter. Its advantage compared to bio-waste includes a relatively homogenous and stable composition. Besides, the grass cuttings have low pollution levels. Such grass cuttings are currently being ploughed into agricultural lands without pre-treatment. This leads to spreading of micro-plastics and invasive exotic plants. A similar technology like the one currently in use by Attero (AD followed by composting) could be applied. This can yield a potting soil material very similar to peat in its properties, low in nutrients and rich in stable organic matter.

- Product related constraints

The market for selling compost in the Netherlands is tight because of the high availability of animal manure. Animal manure is a competing product to compost as an organic fertiliser, in agriculture. In consequence, the true value of compost cannot be materialised by Attero. Export to other countries is difficult because of legislation, e.g. different countries have different quality norms and certificate requirements. The low margin due to the low market price of the compost makes it in return difficult for companies like Attero to invest resources into research and development. In the future, innovation could step up quicker in the composting sector, when demand for compost would further increase.

For more information on Attero's activities, feel free to visit:
https://www.attero.nl

6. BMC Moerdijk (the Netherlands): Incineration of poultry litter

6.1. Brief history and activities of the company

BMC Moerdijk was founded in 2006 as a cooperation between 600 poultry farmers (organised in the cooperative Duurzame Energieproductie Pluimveehouderij (DEP), the farmers' association Zuidelijke Land- en Tuinbouworganisatie (ZLTO) and the energy company Proviniciale Zeeuwse Energie Maatschappij (PZEM NV). It evolved out of the need of the energy sector to find renewable resources and the poultry sector to find a sustainable and reliable destination for their manure. The power plant had its official opening in 2008 (Figure 14). In 2006, the farmers engaged to deliver poultry manure for 10 years and this was renewed in 2018 to run until 2030 (BMC Moerdijk, 2020a). Currently, BMC Moerdijk is incinerating 430 000 tonnes of poultry manure annually, producing electricity and poultry litter ash (PLA). This represents one-third of the total production of poultry manure in the Netherlands. On an annual basis, 291 000 MWh is produced out of which 245 000 MWh is directed into the electricity grid (enough for 70 000 households for one year) and 57 000 tonnes of PLA which is sold as PK fertiliser and fertiliser component (De Leeuw, 2019). The fertiliser is mainly exported to France, Belgium, and the United Kingdom.

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Figure 14. BMC Moerdijk, the Netherlands

6.2. Description of technology

Due to intensive livestock farming in the Netherlands, to protect water resources from eutrophication, strict application limits for P in crop fertilisation are implemented by the government. Not all animal manure produced in the Netherlands can be applied to agricultural fields, some has to be exported to other countries. This export is facilitated with the incineration activities of BMC Moerdijk. Raw poultry manure has a large volume that would create high transport costs, whereas the ash contains concentrated plant nutrients (P and K). This allows energy recovery in the country of origin, the Netherlands, and export of the surplus P and K to countries like France where there is a demand for these nutrients. The incineration process at BMC Moerdijk consists of several different steps (Figure 15):

- At first, the incoming poultry manure (1 200 to 1 400 tonnes daily) is mixed.
- The manure is incinerated to ash at temperatures up to 1000 ° C in a fluidized sand-bed combustor. The process requires an input of 7 000 tonnes of silica sand per year (BMC Moerdijk, 2020b).
- The evolving gases are cooled, filtered and cleaned (electrostatic precipitator for dust removal, a semidry scrubber neutralising acid gasses (hydrochloric acid (HCl), sulphur dioxide (SO_2)) with the help of lime and water and a selective catalytic reductor (reducing NOx with NH_3 to N_2) with the result that only water steam, N_2, and CO_2 are emitted (Billen et al., 2015).
- As the last step to upgrade the ash to a fertiliser that creates less dust in handling, water is added to the ash.

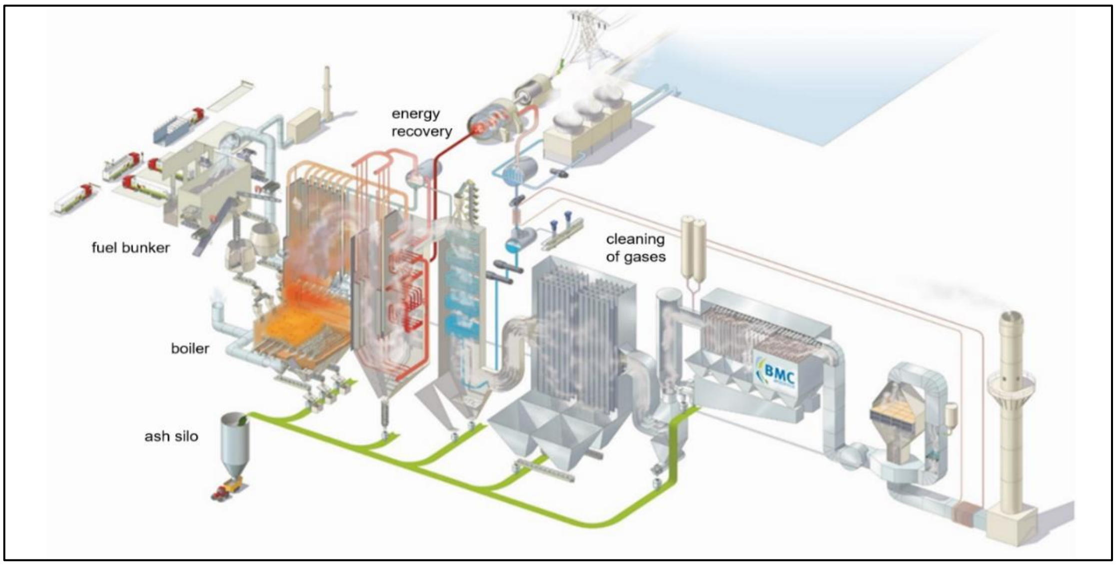

Figure 15. Diagrammatic representation of the nutrient recovery process used at BMC Moerdijk.

There are no plans to increase the capacity at BMC Moerdijk since one-third of the Dutch poultry manure is already taken up by BMC. Therefore, if BMC wanted to incinerate more poultry manure, it would need to pay a higher price for this resource. However, the goal of BMC Moerdijk is to increase the availability of the facility by optimising the maintenance work (cleaning and repairing). In 2019, the power plant was operational for 93 % of the days of the year.

The technology of BMC Moerdijk is implemented at TRL 9 : actual system proven and running in operational environment. BMC Moerdijk receives a lot of requests from outside of the Netherlands with interest in their technology. These parties are looking for sources of renewable energy and options for valorisation of animal manure (surplus). Seeing that governments are giving out funding for renewable energy solutions, there are opportunities to construct similar installations in other countries. One big advantage of the incineration technology compared to other NRTs is the production of a sterile, and thus from a sanitary point of view, a safer fertiliser. The technology should be taken up more by the market also from a Circular Economy perspective. In Europe, there are similar installations only in England and currently one being constructed in Turkey. On a global scale, there are other installations running in Japan.

6.3. Generated product(s) from the implemented technology

Besides energy, the incineration process of BMC Moerdijk has one sole product : hydrated PLA (Figure 16). This ash is used as a PK fertiliser and consists of the ash of poultry manure (75 %), sand (12.5 %), water (10 %), a boiler additive (1.25 %), and lime (1.25 %). In terms of nutrients, it contains about 11% P_2O_5, 12% K_2O as well as 20 % calcium oxide (CaO), 5 % magnesium oxide (MgO), and 7% sulphur trioxide (SO_3). The sodium content is 3 % sodium oxide (Na_2O) (De Leeuw, G.-J., 2019). It is marketed directly as a fertiliser (30 % of the produced ash) or as a component in bulk blending of the fertiliser industry (70 %).

The PLA is a hydrated ash since water is added to the ash at the end of the process. This reduces the dust formation when the ash fertiliser is stored, transported, and applied to soil. The P and K contained in the ash has a high plant availability. This ash is the sole end residue of the poultry manure incineration process. N is currently released as N_2 into the air, but BMC Moerdijk is exploring options to recover this N as a fertiliser or other useful product that can be recycled within the Circular Economy. The energy is produced via a steam turbine feeding an electricity generator.

The current yearly production of BMC Moerdijk is 60 000 tonnes of ash. The ash is blended into compost and into mineral fertilisers. The current destination countries are France, Belgium and United Kingdom. In these countries, the ash has a national authorisation to be sold as a fertiliser (De Leeuw, 2019).

Figure 16. Hydrated poultry litter ash produced by BMC Moerdijk (Nutriman, 2020)

6.4. Implementation constraints

- Technological constrains

In the past, BMC Moerdijk often needed to shut down the entire installation because agglomerations were clogging the pipes. A solution was found for this : an additive that alters the ratio between different components of the ash and thereby agglomerations formed are smaller and softer. Thus, less clogging occurs.

- Production and logistical constraints

In the past, the variations in nutrient contents in the manure (depending on type and age of poultry and farm) and humidity (higher in winter) have caused fluctuations in energy production and ash composition. However, by increasing storage capacity at the site, mixing of different batches of manure is possible and can compensate for fluctuations.

For the future, BMC Moerdijk foresees constraints in their production because of a lack of skilled technical staff. In particular, staff qualified to repair the machinery will be lacking in the future. Besides this, the political discussion around plans of the government to reduce the livestock intensity in the Netherlands, could have an impact on BMC Moerdijk.

- Product-related constrains

The status of the PLA depends on the legal perspective (Waste Framework Directive, Animal By-Product Regulation, Nitrates Directive, national legislation). As the product is not regulated by the current EU Fertiliser regulation, BMC Moerdijk and its customers had to prepare a lot of documents and go through long processes to have the ash registered as a fertiliser in France, Belgium, and the United Kingdom. This process of getting authorisation from an EU Member State could be supported by having the fertiliser status in the country of origin, and not only the end-of-waste status. For the future with the new EU fertiliser regulation, BMC Moerdijk faces the issue that the ash contains in an absolute amount more zinc than allowed, all of which in fact comes from the poultry manure and can therefore not be recognised as an EC fertiliser but only as a Component Material Category (CMC).

- Other encountered constrains

In the planning and beginning phase of the project, BMC Moerdijk received a lot of criticism. With good communication and open exchange, most of these have been resolved.

- BMC was accused of allowing intensification of poultry husbandry in the Netherlands. However, the presence of intensive livestock in the Netherlands is due to efficient logistics, cost-efficient production techniques, and poultry meat demand. The start of BMC Moerdijk had no impact on the size of the poultry sector, also because the costs of poultry manure are limited compared to the other costs of the poultry farmer and sometimes is not even a cost, but a revenue.
- Another criticism was that OM is destroyed and CO_2 is emitted to the air. This is true but needs to be evaluated in a context where society is looking for renewable energy solutions, wants to recover nutrients, and where spreading of manure on land also has disadvantages. A life cycle analysis (LCA) study by De Graaff et al. (2017) assigns this incineration of BMC a CO_2 bonus since it is avoiding the burning of fossil fuel. BMC is exploring options to capture the emitted CO_2 and provide this to, e.g. greenhouses in the Netherlands.

- Currently, N is not recovered during the nutrient recovery process. BMC Moerdijk is investigating if it would be technically and economically feasible to also recover the N.

For more information on BMC Moerdijk's activities, feel free to visit:

https://www.bmcmoerdijk.nl/

7. Groot Zevert Vergisting (the Netherlands) : Acidification and reverse osmosis

7.1. Brief history and activities of the company

Groot Zevert Vergisting (GZV) is an installation for AD of pig manure in Beltrum, in the East of the Netherlands. The AD plant is operational since 2004 with a capacity of 15 000 m^3 and 6.5 MWe, and runs on mesophilic digestion (Figure 17). In 2018, the capacity was increased from 102 to 135 k tonnes of substrate out of which 80 k tonnes is pig manure collected from about 55 pig farmers in the region. The rest is mainly waste from dairy and feed industry. The produced biogas is directly transported via pipelines to a dairy factory of Friesland Campina where electricity is generated, and the heat is used in milk processing (Kunstmestvrije Achterhoek project, 2020 and Systemic project, 2018a).

Figure 17. Aerial view of Groot Zevert Vergisting plant in the Netherlands (Source: Groene Mineralen Centrale, 2020)

In 2019, the 'Green Mineral Centre' was opened at GZV. Its innovation lies in the treatment of the digestate into a large variety of different fertiliser products : NK mineral concentrate, solid phosphate and an organic soil amendment low in P (Systemic project, 2020b).

7.2. Description of technology

After co-digestion of pig manure, the digestate is separated by means of a decanter into a LF and SF of digestate (Figure 18). To derive the NK-rich mineral concentrate, the LF undergoes dissolved air flotation (DAF) and membrane filtration systems that includes microfiltration, RO and ion-exchange. This technology is operational since 2019 (Systemic project, 2020b). To produce solid phosphate and the P-poor soil improver out of the SF, a P-stripper is installed with ‘acid-base approach’. H_2SO_4 is added to release phosphate from the SF of digestate, whereas magnesium hydroxide ($Mg(OH)_2$) or calcium hydroxide ($Ca(OH)_2$) is added to precipitate phosphate (Systemic project, 2020b). Depending on the used base, struvite or calcium phosphate can be recovered. What remains after ‘acid-base’ approach is an organic soil improver with a low P content.

GZV is closing nutrient cycles as regionally as possible by an efficient nutrient use as close as possible to the biogas plant. For this, the components of the digestate are separated to a large degree : the NK concentrate can be used in arable farming in the direct neighbourhood as well as the soil improver which is low in P. With the mineral concentrate, the entire LF of digestate can be recycled : 60 - 89 % of the volume as clean water and 20 to 40 % as NK concentrate (Groene Mineralen Centrale, 2020). GZV expects to use the solid phosphate in the future as a P fertiliser by dairy farmers in the region if the soil P contents decrease due to strict fertiliser limits. Else, the solid phosphate can be sold for industrial purposes.

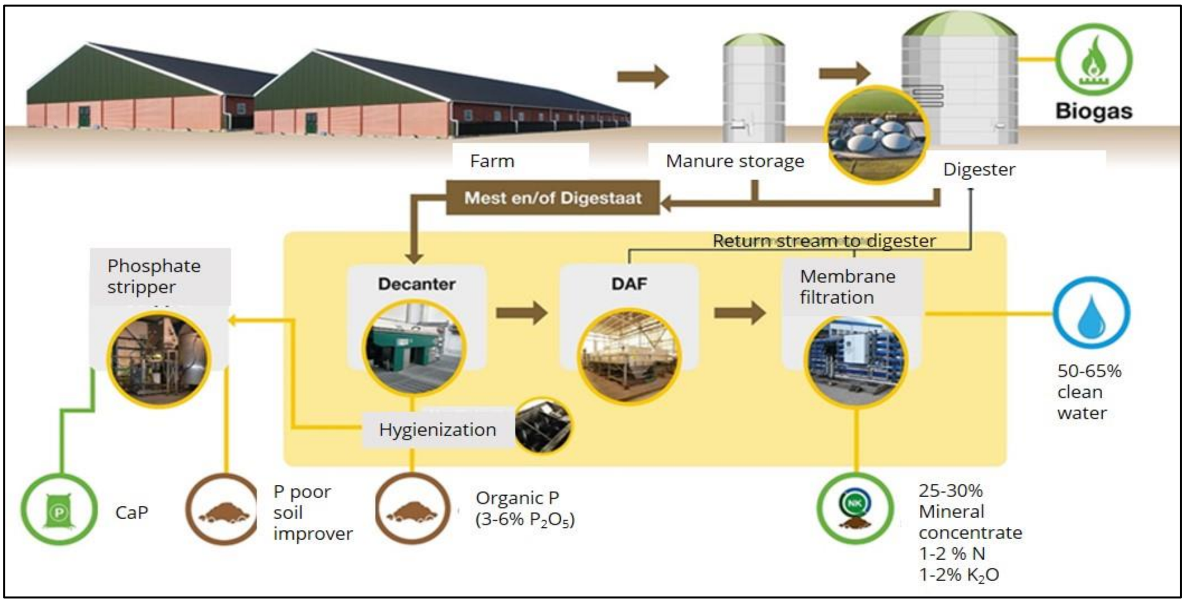

Figure 18. Process description of GZV (adapted to English from Groene Mineralen Centrale, 2020)

All technologies at GZV (AD, treatment of LF and SF) are implemented at TRL 9 : system proven and running in operational environment. There are several installations producing mineral concentrate in the Netherlands and in Flanders. However, with the entire combination of technologies within the Green Mineral Centre, GZV currently has a unique front-runner concept in place.

7.3. Generated product(s) from the implemented technology

The mineral concentrate is marketed as the brand 'Green Meadows fertiliser' (Dutch : Groene Weidemeststof). To increase the N content, other components are added : recovered $(NH_4)_2SO_4$ for fertilisation in early spring and urea later in the season. Currently, it contains 0.8 % N and 0.9 % K_2O. It is a good fertiliser for all arable crops to be used as a complement to animal manure. In the pilot region 'Mineral fertiliser free Achterhoek' (Figure 19), it is currently tested in grass and maize (Canter Cremers, 2019). The 'Mineral fertiliser free Achterhoek' project runs from 2017 to 2021 with the goal to experiment and demonstrate field application and nutrient efficiency of these innovative recovered fertilisers in the field. To carry out the project, a derogation was given by the Dutch government so that N from animal manure origin can be applied above the limit of 170 kg N ha^{-1} y^{-1} of the Nitrates Directive (Systemic project, 2020a). The current production of the mineral concentrate is 60 tonnes per day and GZV has a storage capacity of 10 000 m^3. In the past three years, a lot of effort has been made to improve application technology. It is now injected deeper than in the first trials to lower N emissions to the air.

Figure 19. Field application of the mineral concentrate produced by GZV (source: Kunstmestvrije Achterhoek project, 2020)

Solid phosphate is stripped from the SF of the digestate. The P_2O_5 content is about 14 %. At the moment there is no drying facility in place and the product is taken up by dairy farmers in the region as a P fertiliser. In the future, it will be dried and either sold as a fertiliser as locally as possible, or sold as a component to the fertiliser or other industry. The current daily production is 6 m^3.

P-poor soil improver is the resulting product after P has been stripped out of the SF of the digestate. It is rich in OM (about 89% of DM) and low in P. Therefore, it can be applied to soils in the region and help to maintain or raise soil OM content. It could also replace peat in potting soil. The current hourly production is 4 m^3. The soil improver is being tested for the first time in 2020 by 10 farmers in the region. For this, a derogation applies which allows the farmers to only account for 50 % of the contained P for the P limit and to assume 10 % N efficiency.

7.4. Implementation constraints

Large parts of the technology used by GZV are implemented for the first time at a large scale. Consequently, not everything was running smoothly from the first day and a lot of small details had to still be adapted before production could start. However, the Green Mineral Centre at GZV was also a large investment financed by several investors. It was a constant effort of the project managers to convince investors to keep on believing in the project despite the time it took until production was running and products could be sold.

GZV also already had to change its production objective since the start of the project. In the beginning, the aim was to produce a mineral concentrate with a nutrient concentration as high as possible. However, after the exchange with the farming world and signals from politics and legislation, the objective was changed towards producing a mineral concentrate with the fitting nutrient composition for crop fertilisation. In this way, Circular Economy goals are achieved : fertiliser products are adapted in their composition to regional needs avoiding transport and allowing a nutrient efficient regional use.

For more information on GZV's activities, feel free to visit:

https://www.groenemineralencentrale.nl/nl/groot-zevert-vergisting

8. Conclusion

During the interviews, all six companies stated that bottlenecks in implementation of NRTs are inevitable.

From a technological standpoint, the fact that a certain technology is proven does not mean that implementation issues would not occur. Almost all NRTs are tailor-made as their choice and implementation depends on the existing challenges (e.g. high water content, low N concentration, etc.) that a company has and would like to resolve. Once the aim for installing a NRT is set, search for a technology provider can start. Technology providers are scarce and each provider has their specific technical expertise, which makes it difficult to compare offers. Not all technologies can be supplied by a single provider. The different process steps have to be aligned (volume, concentration, …). This requires intensive start-up testing and tuning, which can last for more than a year and requires financial resources to continue development activities without any revenue from product sales. The choice of technology and an intensive need for tuning can be influenced by the characteristic of the input stream that is treated by NRTs. For example, input streams with high organic load, suspended solids and viscosity can lead to clogging and / or sticking issues. Issues with inorganic impurities in feed material (e.g. compost) are also possible. The installation and implementation of a new process step requires a lot of testing and fine-tuning until the correct set-points and a stable product concentration are obtained.

To achieve optimal production rate, certain technologies require expensive chemicals and solutions, e.g. efficiency of the stripping-scrubbing system depends on the pH of the LF. If the pH of the LF has to be increased, this is an extra cost. Additionally, this NRT also requires acid which entails certain risks and safety measures. When it comes to the logistics of the recovery process and generated products, the situation is also not that simple. Liquid products can contain a significant amount of water, which requires sufficient storage, increases costs of transport and application and poses a risk for soil compaction due to heavy field application machinery. If generated products cannot be applied on the nearby fields due to legal barriers on product use and application rates or a lack of local demand, then they need to be transported over large distances. Furthermore, the variations in nutrient contents in the feed (e.g. manure (depending on type and age of poultry and farm) and humidity (higher in winter)) can cause fluctuations in energy production and product composition. Some companies also foresee constraints in their production because of a lack of skilled technical staff. In particular, staff qualified to repair the machinery will be lacking in the future.

In general, according to the current EU legislation (i.e. the Nitrates Directive), all manure-derived fertilisers are considered to have a status of animal manure. This means that manure-derived products from NRTs compete with animal manure for application on arable land. Moreover, Flanders and the Netherlands have strict N and P application rates. Meaning, in the case of surplus, manure-derived products need to be transported. Export to other countries is difficult because of legislation, e.g. different countries have different quality norms and certificate requirements. Therefore, the status of generated products from the NRTs depends on the legal perspective (Waste Framework Directive, Animal By-Product Regulation, Nitrates Directive, national legislation).

Furthermore, due to a number of bankruptcies in the period 2012-2014, all banks in the region of Flanders (Belgium) withdrew from investments in biogas installations and stopped granting loans for biogas installations and related manure treatment investments. In order to finance the investments, external capital needs to be attracted.

Finally, certain NRTs (e.g. incineration) can receive a lot of criticism from general public. Therefore, personal investment in good communication and open exchange with the public is needed.

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