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SYSTEMIC

Circular solutions for biowaste

2020

Market research in Europe

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Preface

Within the H2020 SYSTEMIC project (Grant Agreement no. 730400) one of the major aims is to explore the possibilities to enlarge the lifetime of available nutrients in biowaste, like manure, sewage sludge, and food- and feed waste streams, in order to meet with the goals of the Circular Economy Package. Besides demonstrating innovative nutrient recovery technologies at large scale biogas plants (pioneers), also ten Outreach Locations and twenty-five Associated Plants from all over Europe are following the performance and business opportunities of the demonstration plants and are interested in the opportunities for their own business case ('first followers'). Each individual biogas plant interested in nutrient recovery and reuse technologies (NRR) should make nutrient products, which meet with the crop requirements in their own region in case they want to apply the products directly on agricultural land. Another possible outcome for these products is to be regarded as secondary resources, which can be used by other industries like e.g. mineral or organo-mineral fertiliser industry.

In order to facilitate implementation of NRR technology at biogas plants, interested in NRR technology a market study was carried out to inspire and inform them about the market opportunities of different types of recovered nutrient products from digestate with current technologies. In addition, a SYSTEMIC nutrient recovery calculation tool (NUTRICAS) has been developed which can be used to estimate the product quality of recovered products of more than twenty NRR cascades, taking into account the specific composition of the digestate of a biogas plant. Both the market study as well as NUTRICAS will help biogas plants take the first steps in designing their own specific business case with NRR.

Yet, marketing of new products is difficult for a number of reasons: product characteristics don't meet with consumer's expectations, little is known about the risks and safe use of the products and many biogas plant owners have no training in marketing digestate and consider this not the main focus of their business.

Moreover, end users have specific demands related to new nutrient products, especially regarding the requirements (specs) on delivery (quality, volume, logistics).

This report focuses on the market study and in particular on (1) current status of digestate processing and nutrient recovery at biogas plants, (2) agricultural demand in nutrients for different regions in Europe, (3) conditions which should be taken into account (legislation and end users) and (4) finally important aspects of a market strategy considering the reuse of recovered nutrients from digested biowaste streams taking into account that the market will change over time, and technologies will improve and often become cheaper over time.

The SYSTEMIC consortium hopes that this report will help biogas plants in finding solutions for their own business case in making products which have value in their own region.

Summary

This market study report is meant to inspire biogas plants and inform them about the market opportunities of different types of recovered nutrient products from digestate with current technologies. It complements the SYSTEMIC nutrient recovery calculation tool (NUTRICAS), to set up new business cases with nutrient recovery.
In the SYSTEMIC project, currently 35 European biogas plants are involved as Demonstration Plants, Outreach Locations and Associated Plants. To illustrate which technologies commonly used, the technologies used to treat their digestate and the produced end products are listed per plant.

In the following chapter, the nutrient demand in different regions in Europe is discussed, depending on the soil nutrient status, livestock density and available manure, regional legislation, crop cultivation and crop nutrient demand. Here, for specific regions recovered nutrient products are suggested that would have a high value in replacing mineral fertiliser complementary to base fertilisation with manure or raw digestate.

Next, the framework conditions regarding the marketing of recovered nutrient products are discussed. Legislative aspects are elaborately treated because they have the potential to open of the existing fertiliser market for these new recovered products and generate value for their producers.
The conditions, requirements, specifications, preferences that different end users have for these products are covered for farmers, mineral fertiliser industries and home gardeners. It involves product characteristics like form, composition, contaminant content and volume.

For these 3 types of end users, the following chapter sets out some specific tips for communication and advertising strategy of these products. Direct contact with the end user and making your product relatable are key when influencing consumer perception and willingness to buy the product. Special attention is given to some actions that could help boost the product's marketability.

The last chapter describes for each SYSTEMIC Outreach Location recovered nutrient products that could have market potential in their region. The consortium briefly makes an estimation of the economic feasibility of the technology implementation required to produce these products for the specific Outreach Location. These basic drafts of business cases with NRR will be discussed with the Outreach Locations while using the NUTRICAS tool and the combined outcome will be evaluated on feasibility.

The first annex of this report gives more information about some of the nutrient products. Information that can be supplemented by other deliverables (reports) produced in SYSTEMIC.
In the second annex some niche markets for recovered nutrient products as discussed. It includes both current and future potential niche markets and describes the barriers still to overcome before recovered nutrients can be successfully made available on these markets.
Entering these markets usually takes a lot of research, testing, finetuning of product, logistics, negotiating, etc. but can eventually render much higher profit margins and encounters less competition.
This is a time-, money- and energy consuming process for which most biogas plants don't have the resources nor are experienced for. Entering these niche markets will need the support of universities, research facilities, consultants, private corporations, funding etc.
The report ends with a positive note: success stories of biogas plants recovering nutrients and stimulating collaborations are described to encourage biogas plants that NRR can be a part of a profitable business case.

1 Recovered products from digestate

In the SYSTEMIC project, currently 35 European biogas plants are involved. Some of them have already implemented technologies to recover nutrients, organic matter or water from their digestate. These plants are listed in Table 1-1, together with the products they produce. For some of them, the story behind the marketing of their products is described in ANNEX III.

The input streams of the digester vary between plants and sometimes within one plant over the years. Often, manure, sewage sludge, bio-waste or slaughterhouse waste is used as main feedstock. All these feedstock types have different compositions and therefore also affect the composition of the digestate. The NRR technologies create new products from this digestate, that could have a higher marketing potential or are more easy to dispose of.
General product characterisations for P-salts, mineral concentrates, solid fraction, calcium carbonate, fibres and purified water can be found in ANNEX I. For the Demonstration Plants, more information about their process and products is available in the SYSTEMIC Factsheets on Demonstration Plants (www.systemicproject.eu). More detailed information will become publicly available in 2020 in the form of report D1.13 Final document on product characteristics, lab results and field trials, and report D1.5 on mass and energy balances, product composition and quality and overall technical performance of the demonstration plants. For outreach plants, more information is online available in the SYSTEMIC factsheets for Outreach Locations.

Table 1-1. Digestate processing steps and end products of biogas plants involved in SYSTEMIC as Demonstration Plant, Outreach Location or Associated Plant

Biogas Plant	**SYSTEMIC Plant**	**Country**	**Process steps**	**Product**
Groot Zevert Vergisting	Demonstration Plant	The Netherlands	Centrifuge DAF Micro filtration Reversed osmosis Re-P-eat	NK-concentrate Dischargeable water P-fertiliser (P-salts) P-poor soil conditioner
AMPower	Demonstration Plant	Belgium	Centrifuge Evaporator Reversed osmosis Dryer Acid air scrubber	Permeate Dried solid fraction Ammonium sulphate
Aqua e Sole	Demonstration Plant	Italy	Ammonia stripper/scrubber	Ammonium sulphate Digestate (low in N)
Benas	Demonstration Plant	Germany	FibrePlus system	Ammonium sulphate Calcium carbonate Fibres Digestate (low in N)
SCRL Kessler	Outreach Location	Belgium	Screw press Dryer	Solid fraction Liquid fraction Dried digestate

Waterleau New Energy	Outreach Location	Belgium	Centrifuge Dryer Nitrification-denitrification Evaporator Reversed osmosis	Dried solid fraction Permeate (process water) Concentrated N(PK)
GMB	Outreach Location	The Netherlands	Centrifuge Nitrification-denitrification Composting Acid air scrubbing	Dischargeable effluent Composted solid fraction Ammonium sulphate
Emeraude Bioénergie	Outreach Location	France	Centrifuge Ammonia stripper-scrubber Nitrification-denitrification Dryer	Ammonium sulphate dischargeable effluent dried solid fraction
Waternet	Outreach Location	The Netherlands	Struvite precipitation Centrifuge Nitrification-denitrification	Struvite Solid fraction (incinerated) Dischargeable effluent
Biogas Bree	Outreach Location	Belgium	Centrifuge Drying Air stripping-acid scrubbing	Liquid fraction Solid fraction Dried digestate Ammonium sulphate
Greenlogix Bioenergy	Associated Plant	Belgium	Centrifuge Lime softener Ammonia stripper-scrubber Nitrification-denitrification centrifuge	Solid fraction Ammonium sulphate Dischargeable water Solid fraction MBR sludge
NDM	Associated Plant	Germany	Screw press Acid air washer Centrifuge Dryer Incineration CO2 stripper Ammonia stripper-scrubber	Solid fraction manure Ammonium sulphate liquid fraction (NPK fertiliser) P-rich ashes Ammonium sulphate
Agro Energy Hohenlohe	Associated Plant	Germany	Screw press acidification Drying greenhouse pelletizer	Pelletized dried solid fraction
Suiker unie Dinteloord	Associated Plant	The Netherlands	Centrifuge Nitrification-denitrification	Solid fraction Dischargeable effluent
AFBI	Associated Plant	Northern Ireland (UK)	Screw press and centrifuge	Solid fraction Liquid fraction
Bioenergy Neukirchen	Associated Plant	Germany	Screw press	Solid fraction Liquid fraction
Lüleburgaz, Agman Inc.	Associated Plant	Turkey	Sedimentation pond	Sedimented solids Digestate
IVVO	Associated Plant	Belgium	Screw press Composting Nitrification-denitrification evaporation	Composted solid fraction Ammonia water Process water
Grupo Biogas Fuelcell	Associated Plant	Spain	Separation	Solid fraction Liquid fraction

Camposampiero, ETRA	Associated Plant	Italy	Centrifuge Nitrification-denitrification	Solid fraction Effluent
Arbio	Associated Plant	Belgium	Belt press -Nitrification-denitrification -decantation tank Filters Reversed osmosis -dryer Mixing with NK concentrate pelletizer	 Effluent Permeate (irrigation water) NPK pellets
Group Op de Beeck	Associated Plant	Belgium	Centrifuge Composting Evaporator Nitrification-denitrification	 Composted solid fraction Ammonia water process water dischargeable water
Stormossen	Associated Plant	Finland	Centrifuge Nitrification-denitrification Composting	 Dischargeable effluent Composted solid fraction
BioStorg	Associated Plant	Belgium	DAF Belt press composting evaporator	 Composted solid fraction Ammonia water KP concentrate

2 Demand for (recovered) nutrients

The demand for nutrients differs from region to region due to the agricultural landscape (crop distribution and rotation) and the nutrient availability in terms of soil fertility status and livestock density (manure production).

To meet with the nutrient demand of a specific crop, farmers are advised to have a standard soil analysis done to determine their soil nutrient status. Based on this analysis a fertilisation recommendation is given. This fertilisation advice states the amounts of N, P, K, and other elements required for the specific (combination of) crop, soil type including the nutrient status, and allowed maximum application rates according to legislation. Table 2-1 shows some crop specific nutrient administration recommendations or limits. These limits for manure-derived nutrients are 170 kg N ha^{-1} $year^{-1}$ in Nitrate Vulnerable Zones or other limits described in country specific Action Plans (art.3.5 of the Nitrate Directive) (Figure 2-1). In some EU countries (like NL, DE, IE, FL-BE), through a derogation, farmers are allowed to apply more nitrogen from animal manure (e.g. derogation on grassland 230 to 250 kg animal manure derived N/ha/year).
The advised amounts of nutrients will often first be supplied with (digested or co-digested) animal manure, since this is a cheap source of nutrients, especially in regions with high livestock density (Figure 2-3). However, the ratio of N : P : K in animal manure does not exactly fit with crop needs and/or legislative application limits. Therefore, mineral fertilisers are used to fill in the remaining nutrient demand as base fertilisation or additionally during the growing season.

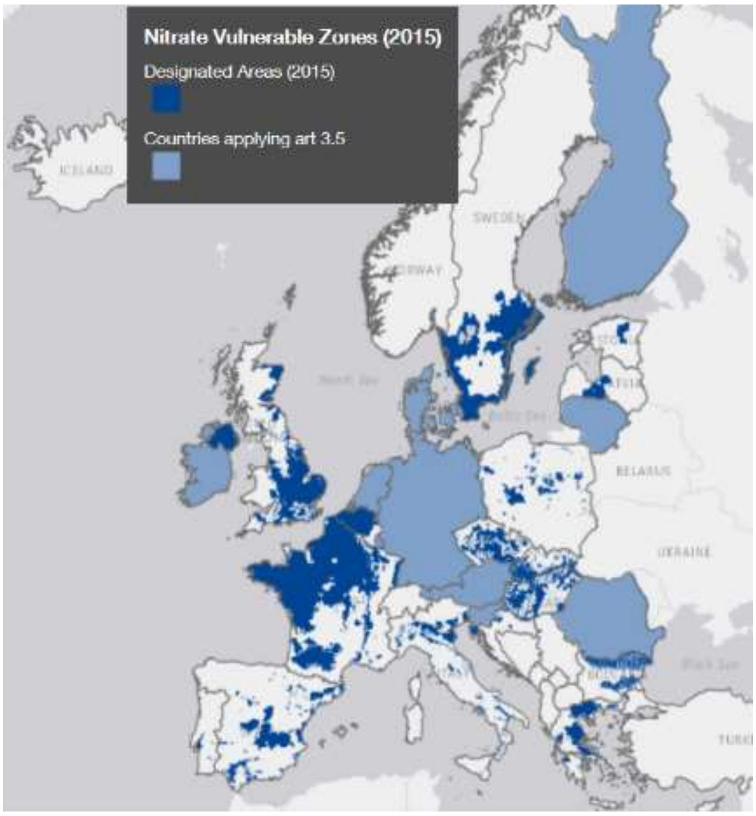


Figure 2-1 Nitrate Vulnerable Zones in Europe (https://water.jrc.ec.europa.eu/portal/apps/webappviewer/index.html?id=d651ecd9f5774080aad738958906b51b)

The potential opportunities of reuse of recovered nutrient products lies in the fact that they can replace these volumes of mineral fertiliser and therefore it can be stated that the demand for nutrients from recycling exists everywhere. Single nutrient fertilisers have a high potential value in situations where they can fill in a gap of a certain specific nutrient. Products with custom-made nutrient ratios fully in line with the crop demand will have therefore prove to have the highest potential to be used.

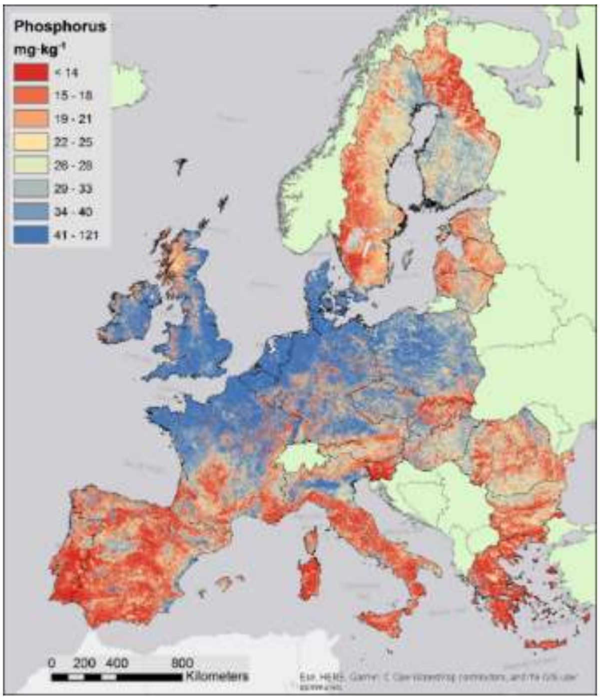


Figure 2-3 Phosphorus in the topsoil in Europe (LUCAS 2009/2012 topsoil data)

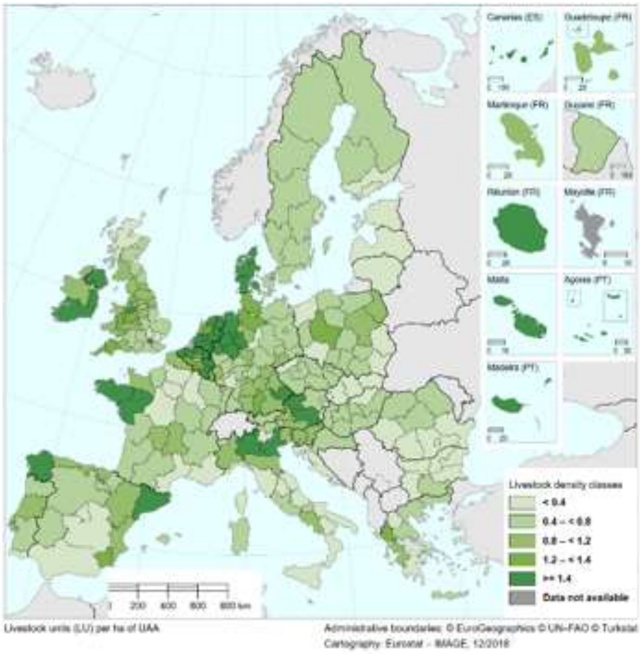


Figure 2-3 Livestock density in units per hectare of utilised agricultural area: cropland + grassland (UAA) (Eurostat: Livestock density by NUTS 2 regions, EU-28, 2016)

In order to map the nutrient demand in different regions in Europe, the most prominently grown crops in Europe have to be determined. For crop production three main types can be distinguished: grassland, cereal and root crops like sugar beets and potatoes (Harms et al. 2019). Figure 2-4, Figure 2-5, Figure 2-6 and Figure 2-7 show how much of the utilised agricultural area: cropland + grassland is occupied by these crops in different regions in Europe and Table 2-1 shows the crop specific N, P and K requirements.

Cereal regions

Cereals like winter wheat require a fertiliser with concentrated N and no to very little P and K (Table 2-1)(Harms et al. 2019).

In cereal regions with a high P soil status and high manure availability, such as in Denmark, North-West Germany, as well as in the Netherlands and in Flanders (*Figure 2-3* and Figure 2-3), products like scrubber salts (ammonium nitrate and ammonium sulphate) can be regarded as single nutrient fertilisers (few P or K present) and because they have nutrient use efficiencies around 80% compared to mineral N fertilisers (100%) (Huygens et al. 2019).

The product can be applied as a starter fertilisation or to top off the base fertilisation up to the level for mineral fertilisers in spring and summer (Vaneeckhaute 2015). Ammonium sulphate is also widely used for chickpeas, both for fertigation and for direct soil application for horticulture (Decaluwe 2016).

When using ammonium sulphate, sulphur can still be the limiting factor for application. Therefore, usually a maximum of 1-2 tonne ammonium sulphate/ per ha is recommended, because a higher sulphur dosing can cause leaching which is harmful for the environment and

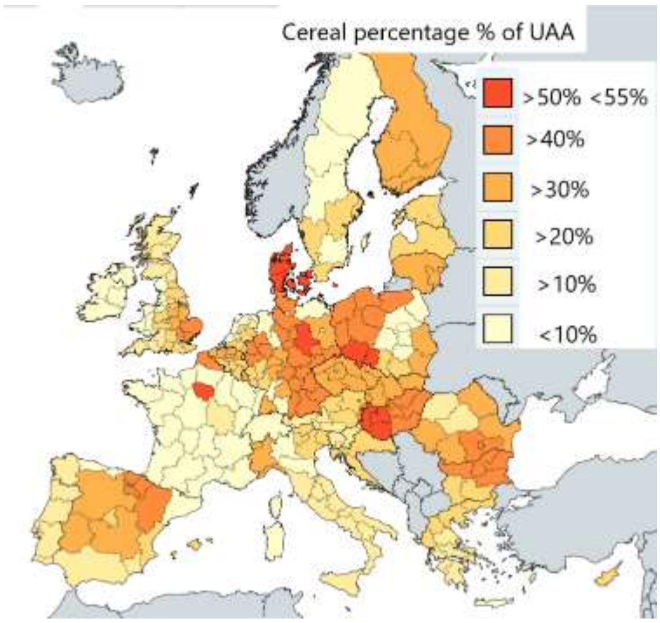


Figure 2-4 Cereals as percentage of UAA(utilised agricultural area: cropland + grassland) (Eurostat: Land cover overview by NUTS 2 regions, type of landcover % [lan_lcv_ovw], 2015)

for drinking water collection. For ammonium sulphate maximum dosages of 1 – 2 m^3/ha are advised (Agreon 2013; Dieleman 2014; Knuivers 2013; Oost 2009).
North and Central France, Sachsen Anhalt (DE), South West Poland, Hungary, South Bulgaria as well as South-East UK, are cereal regions with low animal manure availability. Most of these soils have high P concentrations, yet this phosphorus is only slowly or not available (complexed in the soil). Ca/Mg-P precipitates could be applied as alternative to mineral P up to the maximum allowable level for P fertilisation. nitrogen is the limiting factor for fertiliser application. Struvite may provide a source of slow-release N and P (Vaneeckhaute 2015). Also P-rich solid fractions (locally available or imported from P-rich regions) or NPK concentrates from membrane filtration could be used. However, for these products, the N content also has to be taken in account (Vaneeckhaute 2015).
In Southwest Germany soils are less P saturated (in Bulgaria there is even a P deficit), therefore a slightly higher demand for P and K exists here for cereals in comparison to the previously mentioned regions. Here, more of the previously mentioned products could be used, before reaching the P fertilisation limits.

Corn

Corn requires relatively high nitrogen and potassium, with low amounts of phosphorus (Table 2-1). Yet, a start fertilisation with phosphorus is frequently done, although it is only necessary when a soil has a low P content like in corn cultivating regions Hungary, Bulgaria, South of France, East Austria and Romania) and/or an acid soil pH or the early spring was cold and wet (Abts et al. 2016).
Regions cultivating corn, with high P soil status content, are North and West France, Flanders (BE), South of the Netherlands, North Germany and the South of Denmark. Recovered fertilisers could be again scrubber salts and NK concentrates from membrane technology.
All these corn regions fall partially or completely under the Nitrate Vulnerable zones and therefore, the amount of manure derived N also has to be taken in account when setting up a fertilisation plan.

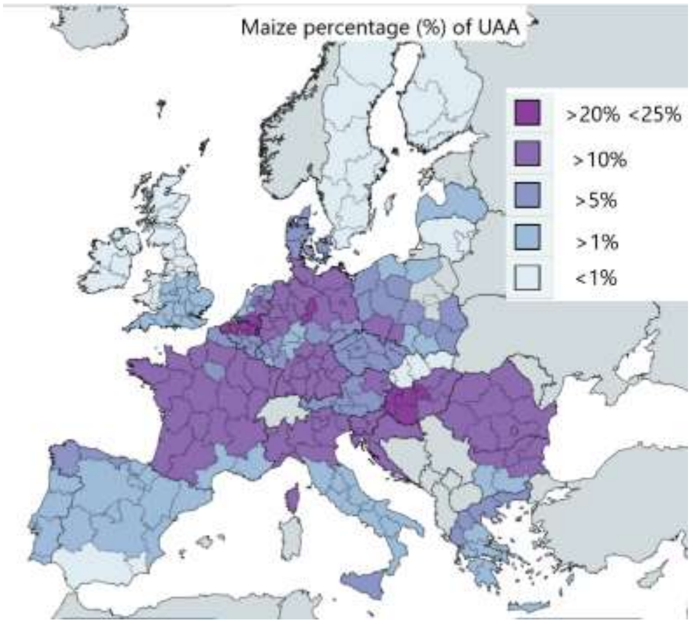


Figure 2-5 Maize as percentage of UAA(utilised agricultural area: cropland + grassland) (Eurostat: Land cover overview by NUTS 2 regions, type of landcover % [lan_lcv_ovw], 2015)

Grass

Grass requires substantial amounts of N (in spring and summer), potassium and sulphur (Table 2-1).
In all grassland rich regions (Figure 2-6) NKS blends or ammonium sulphate could replace mineral fertilisers because they combine all nutrients required (Bussink and van Dijk 2011b; Dijkstra et al. 2012; Rombouts et al. 2014).

When the grass is mowed, 60 - 70 kg SO_3/ha is recommended before first cut. Again, a maximum of 1-2 tonne ammonium sulphate/ per ha is recommended to prevent leaching. Less K supplementation is needed when the grassland is grazed because of K supplementation from the urine (Abts et al. 2016).

Grassland regions in Ireland, when compared to other parts of Europe, have a relatively low demand for all nutrients due to extensive management. This results in low level of fertiliser recommendations. However, soils are relatively low in P so that a moderate demand for P_2O_5 exists (Harms et al. 2019).

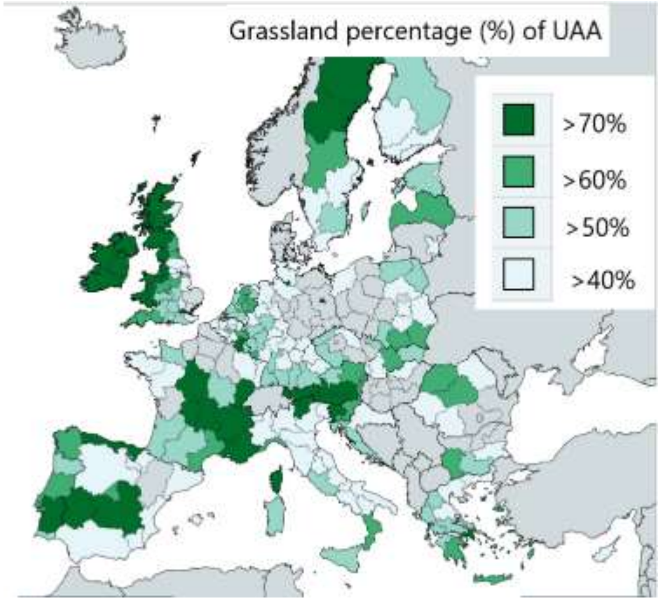
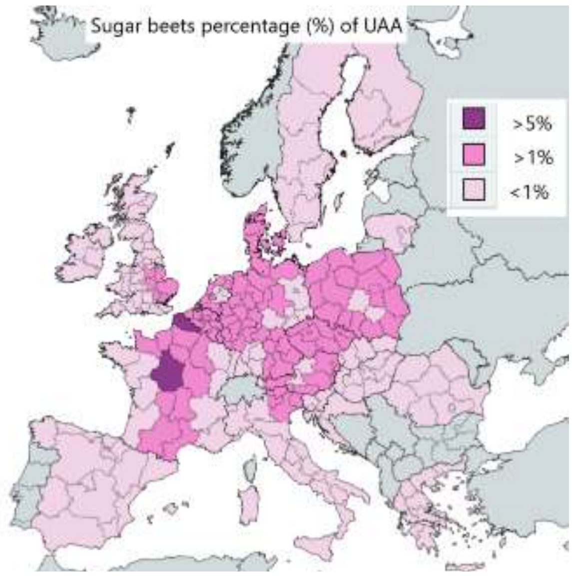


Figure 2-6 Grass as percentage of UAA(utilised agricultural area: cropland + grassland) (Eurostat: Land cover overview by NUTS 2 regions, type of landcover % [lan_lcv_ovw], 2015)

Sugar beets and potatoes

Potatoes are very responsive to P and K and it is necessary to apply these nutrients even at high P soils. Although uptake of P by fodder beet and sugar beet is low compared with N and K, fertiliser P inputs are important because of high response by the beet crop. Sugar beet and potatoes therefore both require a N(P)K fertiliser, for sugar beets the amount of K_2O has to be even higher than for potatoes (Table 2-1). All the P should be applied at sowing time but some of the K can be applied the previous autumn (Teagasc, Jonstown Castle, and Environment Research Centre 2016).

NK mineral concentrates or liquid fraction from digestate could be alternative fertiliser, since all of the regions producing a high share of sugar beets and potatoes are located in livestock intense zones with P rich soils. Only Scotland and South Poland have soils with less P in the toplayer. Solid fraction, struvite or NPK mineral concentrate could have potential in these regions.



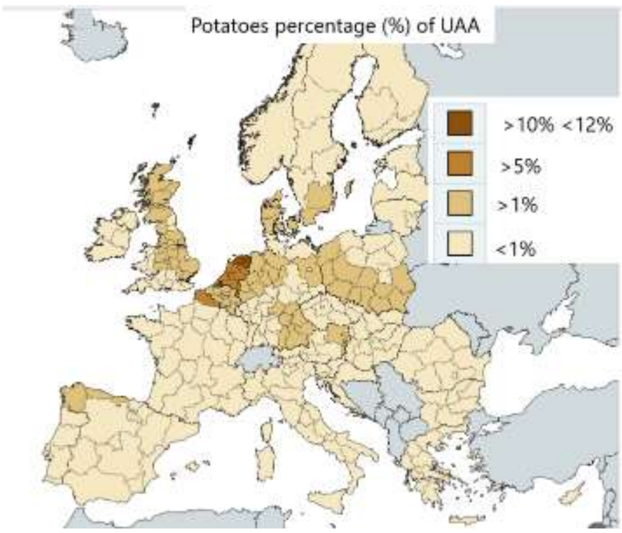


Figure 2-7 Sugar beets (left) and potatoes (right) as percentage of UAA(utilised agricultural area: cropland + grassland) (Eurostat: Land cover overview by NUTS 2 regions, type of landcover % [lan_lcv_ovw], 2015)

Table 2-1. Crop specific nutrient administration recommendations or limits.

Description	**Country**	**Limit/recommendation**	**N (kg N ha $^{-1}$ year^{-1})**	**P kg (P_2O_5 ha $^{-1}$ year^{-1})**	**K (kg K_2O ha $^{-1}$ year^{-1})**
		Grassland			
Administration for optimal dry matter yield after mowing [1]	BE-Fl	Recommendation	450 kg effective N/ha	100-130	350-400
Administration for optimal dry matter yield after grazing [1]	BE-Fl	Recommendation	325 kg effective N/ha	100-130	
Administration after mowing (Peat, loss, sand, clay) [2]	NL	Application standards	265-345	80-120	
Administration after grazing (Peat, loss, sand, clay) [2]	NL	Application standards	300-385	80-120	
[3]	UK	N-max limit	300		
		cereals			
Winter wheat Winter barley Spring wheat Spring barley (on peat, loss, sand, clay) [3]	NL	Application standards	160-245 140 140-150 80	50-120	
Autumn wheat Spring wheat Winter barley Spring barley (on peat, loss, sand, clay) [3]	UK	N-max limit	220 180 180 150		
Winter wheat, assumed yield of 10 kg/ha, soil Index 1-4 [4]	IE	Application standards	100-230 Kg N/ha	0-58 Kg P/ha	0-130 Kg K/ha
		Corn, maize			
Administration in June-July (growing stage) for optimal dry matter yield [1]	BE	recommendation	100-180 kg effective N/ha	2 à 3 kg P_2O_5 ha $^{-1}$ day^{-1}	7 kg K_2O ha $^{-1}$ day^{-1}
Soil index 1-4, assuming a dry matter yield of 15 t/ha and not accounting for slurry application [4]	IE	Application standards	75-180 Kg N/ha	20-70 Kg P/ha	120-250 Kg K/ha
		Potatoes			
Ware potato Seed potato Starch potato (Peat, loss, sand, clay) [2]	NL	Application standards	188-250 120 184-240	50-120 kg P_2O_5 ha $^{-1}$ year^{-1}	
Main crop Early Seed (soil index 1-4) [4]	IE	Recommendation	95-170 80-155 80-155 Kg N/ha	50-125 50-125 85-125 Kg P/ha	120-305 60-150 65-245 Kg K/ha
		Sugar Beets			
Administration in August-November for optimal dry matter yield [1]	BE-Fl	Recommendation	160 kg N/ha	110 kg P_2O_5 /ha	310 kg K2O/ha

(On peat, loss, sand, clay) [2]	NL	Application standards	116-150	50-120	
[3]	UK	N-max limit	120		
soil index 1-4, different rainfall amounts [4]	IE	Recommendation	60-185 Kg N/ha	20-70 Kg P/ha	80-320 Kg K/ha

[1] (Abts et al. 2016)

[2] https://www.rvo.nl/onderwerpen/agrarisch-ondernemen/mestbeleid/mest/tabellen-enpublicaties/tabellen-en-normen 2017

[3] (GOV. UK, Department of Enviroment 2018)

[4] (Teagasc et al. 2016)

https://www.teagasc.ie/crops/soil--soil-fertility/crop-n-p-k-advice

3 Framework conditions

3.1 Legislative aspects

If a product will be used directly as fertiliser or as secondary raw material for the production of fertilisers, different European and National rules for marketing and application need to be taken into account.

These legislations came into force to protect the environment and fair trade in the EU. In general it can be stated that the Fertilising Products Regulation, the Waste Framework Directive, REACH and the Nitrate Directive are the most important legislation aspects to accomplish with respect to European market for secondary nutrients and enhance circular economy.

In the following paragraphs, the main regulated aspects posed by of each those legislations are shortly summarized with possible options (already in progress) to facilitate marketing and use. More in depth information on this topic can be found in "D 2.1 Report on regulations governing AD and NRR in EU member states" [1].

3.1.1 European trade of recovered fertilising products

The Fertiliser Regulation 2003/2003 (FR), defines and lists inorganic fertilisers (primary, secondary and micro-nutrients), liming materials and regulates their market placement by establishing criteria to be marketed as a mineral fertiliser in the EU:

- comply with an existing type designation (single or composite) from the Regulation;
- meet the corresponding minimum composition requirements (e.g. 3% N, 5% P_2O_5 and sum at least 15%, depending on the type);
- chemically obtained;
- no addition of organic nutrients of animal or vegetable origin

The existing FR fails to include organic fertiliser products and secondary raw materials which would otherwise be disposed of as waste. Therefore, a new Fertilising Product Regulation has been published (25th June 2019), but the implementation will take until the 16th of July 2022, i.e. when the current FR ends.

The new FPR sets out common rules on converting bio-waste into raw materials that can be used to manufacture fertilising products and it defines safety, quality and labelling requirements that all fertilising products need to comply with to be traded freely across the EU. Producers will have to demonstrate that their products meet those requirements, as well as limits for organic contaminants, microbial contaminants and physical impurities before affixing the CE-mark.
The new rules will apply to all types of fertilisers to guarantee the highest levels of soil protection. The Regulation introduces a limit for cadmium in phosphate fertilisers of 60 mg/kg P_2O_5.

As some fertilising products are not produced or traded cross-border in large quantities, the European Commission (EC) is proposing optional harmonisation: depending on their business strategy and type of product, manufacturers can either choose to CE mark their product, making it freely tradable in the single market according to common European rules, or have it traded in one member state according to its national standards. It would also be possible to create a "mutual recognition" agreement with a neighbouring country to market it across the border.
Currently the EC is implementing the different administrative bodies that are needed to have conformity assessment for products, market surveillance, development of methods of analysis for each product etc. On a national level, by 25th of March 2020, the member states each have to appoint certified notifying bodies which will be assessing the products' conformity with the regulation.

[1] https://library.wur.nl/WebQuery/wurpubs/fulltext/476673

To be able to comply with the FPR, products from animal manure have to reach an end point in the manufacturing chain ("end-of-manure-status", animal by-products regulation).
The new Regulation has annexes with lists of Component Material Categories (CMC) for CE labelled fertilisers from organic and inorganic materials, i.e. products that have reached the end-of-waste status.
A provision of CMC 10 (Products derived from animal by-products) is foreseen for certain animal by-products like products derived from manure, having reached the end point of the manufacturing chain (excluding Cat 1 animal by-products). However, until today CMC 10 still needs to be completed.

3.1.2 Fertiliser application recommendations and limits

Several regions in Europe with intensive livestock farming suffer from excessive concentrations of phosphorus in the soil and nitrates leaching to groundwater and surface water, which must be controlled to prevent eutrophication of water bodies. Excessive potassium application can lead to salination of the soil and increased losses to waters.
To prevent these environmental burdens, National regulations or recommendations are implemented , which often depend on field conditions (crop type, the soil type and the soil nutrient status) (Harms et al. 2019).

Beside different National regulations and recommendations, the Nitrate Directive (91/676/EEC) provides the regulatory framework for protecting ground and surface water from nitrate pollution in nitrate vulnerable zones and have to be implemented within the national law of EU members.

The main protective measure is limiting the application of total N coming from animal manure to 170 kg/ha/year. This also includes recovered nitrogen fertilising products derived from manure, even if they are (agronomically and environmentally) not significantly different from a chemical fertiliser like recovered ammonium sulphate. However, the SAFEMANURE will give new advices how to deal with such products (see section 3.1.5).

3.1.3 Derogation on application limit of 170 kg N/ha/year

In some EU countries (like NL, DE, IE, FL-BE), it is possible to apply for a derogation, to be able to apply more nitrogen from animal manure (e.g. on grassland 230 to 250 kg animal manure derived N/ha/year). For this, different conditions, like mostly a high share of grassland surface, must be fulfilled. The derogation is re-evaluated after a certain period and is valid for a limited time period.

3.1.4 Pilots in the Netherlands

In the Netherlands, two pilots are running where a different approach is used in order to test the environmental risk and agricultural aspects of recovered N products.
In 2009, some manure processing plants were producing mineral concentrates with membrane technology (all reversed osmosis). The farmers organisation (LTO,) urged the ministry to negotiate with the European Commission conditions under which the mineral concentrates could be used above the limit of 170 kg N/ha/year but within the total N application limit (manure N and mineral N fertiliser) (91/676/EEC).
This was framed in a 2-year pilot project ("Pilot Mineral Concentrates") to investigate the agronomical, economic and environmental aspects of these mineral concentrates from animal manure.
The EC approved the request, under the following conditions:

- Maximum 10 companies [2] could were allowed produce the mineral concentrates.

[2] https://www.rvo.nl/sites/default/files/2019/01/Deelnemende-producenten-onderzoek-mineralen-concentraat.pdf

- They are acknowledged as producer via the Implementing Regulation for the Fertilisers Act and use reversed osmosis.
- A group of independent researchers (WUR) provide guidance, conduct field trials and report on the agronomical, economic and environmental aspects.
- The mineral concentrates could only be used on an area of maximum 20.000ha
- The producers and farmers of the pilot have to be registered at the Netherlands Enterprise Agency (RVO.nl) who will monitor the use of mineral concentrate.

After two years, a continuation of the pilot was approved.

- From 2014 onward, the mineral concentrates produced had to comply with quality criteria to continue the pilot testing:
  - Minimum 90% NH4-N
  - Minimum ratio total N:P2O5 of 15:1
  - Minimum electrical conductivity 50 µS/cm

From 2018 to 2021, the pilot will continue to gather more data on product quality, emissions of pathogens and residues of veterinary medicines in the permeate and to improve the stability of the production process.

In 2017, another pilot (Area-oriented "pilot Mineral Fertiliser-free Achterhoek") was set up which will run until 31 December 2021.
The goal of this pilot is to produce recovered nutrient products from manure, digestate, digested wastewater treatment sludge and blend them to custom-made fertilisers with nutrient composition fitted for grass or corn in the region. The amount of added mineral nitrogen in the blend should be as low as possible. This way, surplus application of S and potassium would be avoided, and disposal would be restricted to the region of the Achterhoek, hereby eliminating (long distance) import of fertilisers and export of manure -and digestate products.

- Produced products that can be used or blended are mineral concentrate, ammonium sulphate, ammonium nitrate.
- The recovered products are produced by 2 producers: GMB BioEnergy and Groot Zevert Vergisting or mineral concentrates from the 10 producers from the pilot mineral concentrates.
- Monitoring quality of products -nutrient levels, contaminants (pathogens, residues of antibiotics)- by independent researchers (WUR).
- 10 users have already registered and maximum 150 users can register at the Netherlands Enterprise Agency (RVO.nl) who will monitor the use of the products.
- The products could only be used on an area of maximum 7500 ha.
- Users using the products of GZV (i.e. manure derived products) can apply these above the limit of 170 kg N/ha.year but within the N application limit (91/676/EEC).

3.1.5 SAFEMANURE

The results of both pilots will contribute to a permanent provision of the Nitrate Directive for the use of recovered N-fertilisers from animal manure.
In this regard, the European Commission assigned in 2018 the Joint Research Centre (JRC) to conduct a 2-year study ("SAFEMANURE") to set up criteria for safe use of RENURE (REcovered Nitrogen from manurRE) products in Nitrates Vulnerable Zones above the threshold established by the Nitrates Directive (i.e. 170 kg N ha^{-1} per $year^{-1}$) (91/676/EEC).

The study will include a literature study, biogeochemical modelling, analysis and comparative pot- and field tests of different manure products provided by Member States.
Provided products include among others (solid/liquid fractions of) digestate/raw manure, reverse osmosis/mineral concentrates and nitrogen salts recovered from stripping-scrubbing.

As a result, SAFEMANURE suggests criteria related to the composition of the RENURE. More specific: mineral N:TN ratio ≥ 90% or a TOC:TN ratio ≤ 3 and Cu: 300 mg/ kg dry matter, Hg: 1 mg/ kg dry matter and Zn: 800 mg/ kg dry matter. Use-specific criteria are not explicitly mentioned. SAFEMANURE does suggest that Member States should take the necessary provisions so that the timing and application rates of RENURE and other fertilising materials are synchronised with plant NPK requirements, and to prevent and minimise nutrient leaching and run-off losses, e.g. by implementing the use of cover/catch crops if appropriate.

The RENURE products are considered technologically neutral, meaning that any product recovered from manure complying to the criteria would be able to be applied above the threshold established by the Nitrates Directive (91/676/EEC).

During a Stakeholder workshop on 30 January 2020 in Seville, the criteria were discussed with stakeholders from the sector. The final report is expected May 2020 and should guide the Member States to enforce good agricultural management practices to the application of these products.

4 Conditions required by end users

In this report, three general types of end users are identified: (1) farmers and (2) horticulturalists, home gardeners and (3) mineral fertiliser industries. Figure 4-1 shows the three types, with certain aspects they regard as important for recovered fertilisers. These aspects are discussed in detail in the following paragraphs.

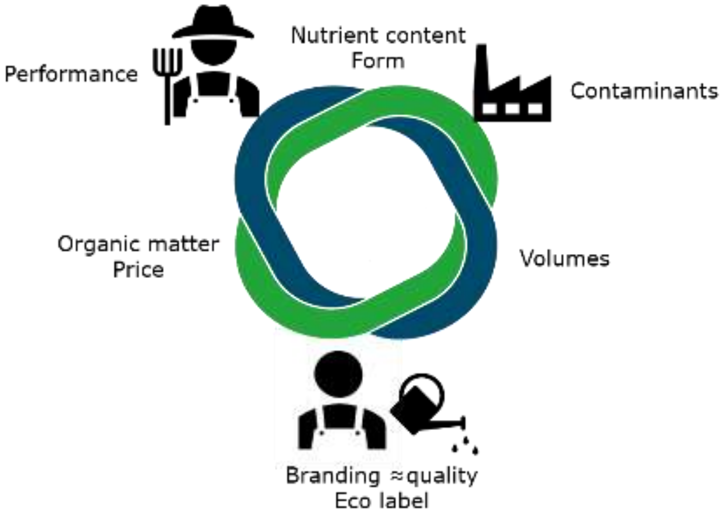


Figure 4-1 Three groups of end users for recovered nutrient products and their preferences.

4.1 Well defined product quality

Farmers like to use a product from which the composition and nutrient availability is well known. For example, the nutrient concentration and ratio are both rated as highly important by farmers and gardeners and for farmers specifically, certainty on the mineral and total N content and the N mineralisation rate of organic fraction of the product (Dahlin et al. 2016; Power et al. 2019; Tur-cardona 2015).

Unfortunately, the N, P, K concentration of products from digestate can vary largely. This is one of the primary barriers for farmers to use organic fertilisers (Case et al. 2017; Tur-Cardona et al. 2015). Therefore, it is crucial, as a producer of recovered nutrient products, to be transparent about the composition of the product, especially if it doesn't meet fully with the criteria of the end users.

Mineral fertiliser industries/producers need to comply with strict regulation, guaranteeing a product with constant composition, high purity and stability over time. Table 4-1 gives a rough indication of the quality of recovered nutrient products (as secondary raw material, expected by mineral fertiliser producers. They expect the secondary raw materials to have a similar quality as the primary resources they are currently using, because of the quality standards their customers are currently expecting from the end product.
A constant quality of the secondary raw material is also necessary for a good integration in the production process. Heterogeneous products with variable composition would repeatedly require a constant finetuning of the following process steps. Often the technical boundaries of the systems producing these secondary raw materials from digestate, limit the production of this kind of homogeneous and pure products. If this is the case and constant quality cannot be delivered, the amount of heterogenicity per product and contaminants should be mapped and the error margin should be determined, informing the mineral fertiliser producer of the quality and potential risks for the process.

A better reproducibility of the products could be achieved by finetuning the pre-treatment steps or by adjusting the nutrient content by making blends with products with a more stable concentration like ammonium sulphate, ammonium nitrate, ammonium water or solid fraction. Blending products also answers better to the differentiated demand of the consumers by making high variety of products.

Table 4-1. Indicative concentrations of nutrients in secondary raw materials requested by mineral fertiliser producers. Ntotal= total nitrogen, NH4-N= ammoniacal nitrogen, P2O5=ortho-phosphate, K2O=potassium oxide, DM=dry matter

	Solid secondary raw material [1]	**Liquid secondary raw material** [1]	**Ca-phosphate** [2]	**Struvite**[2]	**P-salts** [3]
Form				>2 mm	Powder or granulates
% solids	-	<3	As high as possible		As high as possible
% Ntotal	>10	>5			
%NH_4-N			Max 30 (3g/kg)		
% P_2O_5	>10	>5	>6 <10, but only if dry product		>9,2
% K_2O	>10	>5			
% DM	>85	-			

Desirable valuable mandatory

1 (Brañas and Moran 2016)

2 (personal communication 2018)

3 (Postma et al., 2011)

4.2 Contaminants

4.2.1 Organic matter

In contrast to mineral fertilisers, digestate products contain organic matter, from which a (large) part does not break down during the first year of application, hereby contributing to the soil structure, biodiversity and less soil erosion. Farmers are slowly realising the importance of organic matter for the soil (Power et al. 2019).

Mineral fertiliser producers require low levels of organic matter (e.g. carbon) in a secondary raw material especially in combination with nitrate (nitrogen), because carbon can be a catalyst for explosions in certain production processes and the combination of high levels of nitrate and organic matter can cause self-combustion. Additionally, the presence of organic matter reduces the efficiency of the polymer added to extract impurities.

4.2.2 Pathogens and heavy metals

Some farmers have the prejudice that products (from manure or organic waste) contain large amounts of animal pathogens or heavy metals. Nonetheless, this is probably only a perception, since analyses on mineral concentrates have shown that these were present in traces or absent altogether (Ehlert, Hoeksma, and Velthof 2009).

Analyses performed in the framework of the SAFEMANURE study, showed that the 8 mineral concentrate samples complied with the proposed levels for Cu and Zn. Although the limit for Hg (1 mg kg-1) was exceeded by 70% of the mineral concentrate samples. It is still internally discussed if the analytical method used, was reliable and reproducible.

The measured concentrations for Hg were similar to those in raw manure (mg Hg/kg dry matter). Thus, it could be assumed that mercury is preferentially distributed towards the liquid fraction during manure or digestate solid-liquid separation, although advanced solids removal and/or reverse osmosis processes may reduce Hg accumulation in mineral concentrates (Huygens et al. 2019).
Tests on struvite recovery from human urine showed that struvite without organic micro-pollutants and limited amount of metals could be recovered (Nuresys; Ceulemans and Schiettecatte 2013).

Mineral fertiliser producers expect low levels of heavy metals in secondary raw materials. These specifically concern iron (Fe), metals that can volatize during the production process (Zn, Pb, Cd, Sn) and chloride, which can cause corrosion. Cu and chlorides can – similar to carbon- be catalysts for explosions in certain production processes.

Unfortunately, when extracting phosphorus from secondary raw materials, obtaining a pure end product can be difficult, because often a mixture of P-salts (and often also a part organic material) are retrieved from digestate, manure or WWT sludge which first have to be acidulated or transformed into phosphoric acid which in turn can be further transformed. This process dissolves e.g. Mg from struvite, which will be transformed to Mg-sulphate in the process. This is an unwanted component which needs to be removed and therefore does not make struvite salts an interesting secondary P resource for chemical industry. Acidulation also dissolves the heavy metals present in the P-salts. A large amount of heavy metals therefore represents a high extraction cost (personal communication VCM, 2015).

Calcium phosphate ($Ca_3(PO_4)_2$) could potentially be of interest, but problems remain with granulation and there are issues with the extraction and production of clear crystals (Lebuf and Elsacker 2015). Calcium is highly preferred as raw material by the P fertilising industry. Furthermore, calcium phosphate is used as resource for the producing of calcium sulphate (gypsum) for plasterboards. Therefore, it is important that it contains no iron, because iron phosphate is a not well soluble mineral phosphate and it could alter the colour of the plaster to brown. Absence (plasterboards) In the last case a of $CaCO_3$ is also required, since this would produce foam during the process.

Anyhow, some fertiliser companies are open to analyse a sample and feedback on how the concentration should be adjusted and which impurities should be resolved (personal communication VCM, 2018).
Some fertiliser companies are even more flexible and claim to be able to use all kinds of phosphorus streams, preferably with high P content. This is because the impurities of the relatively small recovered phosphorus stream will be diluted during the process (Notenboom, Helmyr, and Van der Zandt 2017).

In the industrial practice, ammonium sulphate is a common by-product and will most likely some impurities from different sources. The same counts for recovered ammonium sulphate from digestate.
For use in agriculture these impurities are regarded negligible, but to be able to create a value for this product in industry, and to for example crystallize it, a high concentration (>20%) and high purity is required (GEA 2010).

Table 4-2 gives an indication of quality requirements related to contaminants for recovered nutrient products set up by mineral fertiliser producers.

Table 4-2. Indicative criteria for contaminants provided by mineral fertiliser producers. DM=dry matter, TOC= total organic carbon, C = carbon, MgO=magnesium oxide, CaO=calcium oxide, SO_3=sulphur trioxide

	Recovered nutrient products [1]	**P products for Non-food uses** [2]	**P product For feed** [3]	**P product food and beverages** [3]	**Solid secondary raw material** [4]	**Liquid secondary raw material** [4]	**Ca-Phosphate** [5]
DM%					>85	-	
TOC%					<2	<2	
C%	Max 0,1% when 100% recovered products are used						<5
MgO%		<5ppm			>2	>1	
CaO %		<5ppm			>2	>1	
SO_3 %				<3400 SO4	>2	>1	
Fe %		<5ppm			>1	>1	
Mn %					>2	>1	
Zn (mg/kg)					<400	<400	Not present
Cu (mg/kg)					<100	<100	Not present
B (mg/kg)					>1000	>1000	
Mo (mg/kg)					>1000	>1000	
Cd (mg/kg)	Max 10%(w/w)			<3	<10	<10	Not present
As (mg/kg)			<40 ppm <8000ppm	<3	<40	<40	Not present
Pb (mg/kg)				<3	<150	<150	Not present
Al (mg/kg)					<1500	<1500	Not present
Cr (mg/kg)					<100	<100	Not present
Cr V (mg/kg)					0	0	Not present
Hg (mg/kg)				<3	<2	<2	Not present
Cl g/kg				<600			0,15
Volatile acids				<30			
SiO_2							As low as possible

Desirable valuable mandatory

1 (personal communication, 2014)

2 (Schipper, W., 2013. Personal communication)

3 (Dikov et al. 2014)

4 (Brañas and Moran 2016)

5 (Personal communication 2018)

4.3 Form

Today, farmers depend on the availability of local agricultural contractors with equipment that can spread the products competitively. Therefore, farmers will prefer to use a dry, granulated or pelletized, concentrated fertiliser where they can, because of the ease of application and logistics (Jacobsen, Bonnichsen, and Tur-cardona 2017). Respondents of a survey of European farmers mostly prefer solid fertilisers, while the Eastern farmers also expressed preferences for semi-solid fertiliser products like digestate (Tur-cardona 2015).

The recovered nutrient products are frequently liquid products. In case of low levels of nutrients, volumes can become high which can hinder practical application. For example, on heavy soils (like clay) it is not advisable to spread large weights and liquid products. On lighter soils (sand, loam,…) liquid products have more opportunities (Smit, Prins, and Hoop 2000).
Administration with a sod injector, towing machine, arable injection or a tanker with trailing hoses are perceived by farmers as convenient for low-emission administration of liquid products (de Hoop et al. 2011).

For garden purposes, granulates and powder are favoured over larger forms and viewed positively since they could be worked into the soil easily and the products would not stand out aesthetically. A downside of the smaller sized product was the creation of dust. Smaller product forms are preferred over larger sizes due to the possibility of a more even and simple distribution. Liquids are preferred when it comes to small quantities for example for flowers and plants in pots (Dahlin, Nelles, and Herbes 2017).

When used as secondary raw material there are limitations set to the water content in function of treatability. For this reason, preferably dry, inorganic streams are used (Ceulemans and Schiettecatte 2013; Lebuf and Elsacker 2015). Additionally, some mineral fertiliser producers do not have the equipment to pelletize and can therefore not process sandy or slurry-like products.
Others are willing to accept slurries but prefer dried products because of the cost for logistics and drying. Organic fertiliser companies producing pellets can only handle solid products in their process lines.
The amount of struvite that can be added to organic fertilisers to improve the P content is limited, since struvite is not "sticky" enough to press in large quantities and the N/Mg/P ratio is not in line with products expected by the costumers. Others claim that they can pelletize struvite, but only when it contains more organic matter (personal communication, 2018).
There is an interest in N-containing liquid products, but mostly only a limited amount (10%) can be mixed with other products. Therefore, the N products would need to have a sufficiently high concentration to have an added value as secondary raw material (personal communication, 2018).

4.4 Volumes

Most digestate derived products are liquids with low concentrations of nutrients and the related transportation costs often hinder distribution over long distances (Huttunen, Manninen, and Leskinen 2014). Furthermore, spreading larger volumes might influence soil compaction, soil structure and crop damage. On the other hand, the current agricultural machinery also has limits on the practical application of small volumes (e.g. <10 tonnes/ha). Administering concentrated products require the injector to dose small values, hereby driving faster, which could cause e.g. wheat to be teared loose (de Hoop et al. 2011). In general, farmers prefer volumes comparable to their mineral fertiliser (Tur-cardona 2015).
If the product is approved by the farmers, it is important to be able to secure a stable supply. The ease of availability of digestate products is one of the most important advantages of digestate products according to Danish farmers (Case et al. 2017).

Fertiliser companies also require a constant supply of large volumes of secondary raw materials to keep the process line running. This is estimated at minimum 10% of annual volume of the primary resource they process.
To adjust the production process to the impurities of the batch, a minimum amounts of 20.000 tonnes can be demanded (personal communication, 2014).
Some mineral fertiliser producers are willing to accept smaller amounts, if they are compensated by a higher gate fee and research results on lab scale towards the technical possibilities. This to provide a guarantee against damage and contamination of their production process.
Table 4-3 gives an indication of required volumes of related nutrient products set by mineral fertiliser producers.

Table 4-3. Indicative values preferred volumes and transport costs.

	Solid secondary raw material [1]	**Liquid secondary raw material [1]**	**Ca-phosphate [2]**	**Struvite [2]**
Tonnes/year	>5000	>5000	200 (P_2O_5) 1000 (80%DM)	1000
Transport costs	<15€/tonne	<15€/tonne		

1 (Brañas and Moran 2016)

2 Personal communication, 2018

4.5 Price

In many regions, price is the determining factor for farmers to use a product. This mainly has to do with the fact that they are unfamiliar with alternative products and don't see their value (yet). However, there is increasing interest for clean food and the way it is produced, and consumers buying food based on the quality. This is already the case in Scandinavian countries (personal communication Atria, 2019). However, this profit does not find its way back to the farmer yet. Until this happens, farmers will not be eager to pay for recovered nutrient products according to their nutrient value.

For products farmers are familiar with, the price payed per unit of N or P or K is a factor rated highly important (Power et al. 2019). When making a well-considered price estimation, one also has must consider the cost for application technique and maximum amount that can be applied each time within a growing season. (Gl Velthof 2011) suggest minimally 10% lower than the price of mineral fertilisers and application cost. (Jacobsen et al. 2017) concludes that it is difficult to get farmers to pay more than 50% of the mineral price for a bio-based product (Table 4-4).

Home garden products are mostly specialized fertilisers and can therefore be sold at much higher prices. However, this does not necessarily mean higher profit margins. These products incur additional manufacturing, packaging and marketing costs and, in addition, up to 60% of the remaining margin may be taken by the retailer (Dahlin, Herbes, and Nelles 2015; Dikov et al. 2014).
The consumer group of the serious hobby gardeners are prepared to pay a higher price for products of premium brands (e.g. that are perceived to be of premium quality) (Dahlin et al. 2017). When purchasing smaller quantities, the importance of the price per unit decreases. However, when larger quantities are required, the price per unit becomes increasingly more important.

Mineral fertiliser producers usually are only willing to pay a price for recovered nutrients that is lower than what they currently pay for their primary nutrient resource. They find this necessary to balance the investment costs needed to adjustments their production process to the secondary raw material of inferior quality.

Reference	**Product**	**Suggested price**

(Notenboom et al. 2017)	Struvite from wastewater treatment in the Netherlands	65€/ton Excl. transport cost
(Ceulemans and Schiettecatte 2013)	Struvite from wastewater treatment in Belgium	50-90€/ton
(NuReSys, Waregem, BE, personal communication 2013)	Struvite from wastewater treatment in Belgium	45€/ton
(Bolzonella et al. 2017)	ammonium sulphate (6% N, 30% ammonium sulphate)	30 €/m3
(Dikov et al. 2014).	P-salt product that more or less meets with the quality requirements of the company	Same price as phosphate rock i.e. 176-327€/tonne P2O5)
(Bussink and van Dijk 2011a)	struvite	½ to 2/3 of price TSP
(VCM and Fraunhofer IGB 2015)	P-salt	50€/ton
Pilot Mineral concentrates NL **2009** **2010**	Mineral concentrates Price payed by farmers	 1,25€/ton 1,19€/ton
Personal communication SYSTEMIC plant, 2018	Ammonium sulphate solution	10-25€/ton

Table 4-5 gives an overview of indicative prices for recovered nutrient products. The price will be strongly influenced by the product quality and contaminants, transport cost, volumes etc.

There are very few companies from which the core business is the marketing of recycled nutrient products. The products they trade, will not have to comply with high quality standards, but the profit margin will be correspondingly low.

Table 4-4. Willingness-to-pay for recovered nutrient products based on literature and surveys.

Source	**Product**	**Suggested price**	**Remark**	**Spreading cost**
(Dodde 2012).	Mineral concentrate (7,12 kg N/ ton; 9,07 kg K2O/ ton)	2€/ton	Grass or corn	
(G. Velthof 2011) The current price of CAN, TSP and KCl(60%) are respectively is 0.23€/kg, 0.40€/kg and 0.33€/kg (august 2019)(Blokland 2019)	N-rich products	Minimally 10% lower than price of CAN i.e. 210 €/ton		Application costs similar to those of mineral fertiliser application: estimated 2,5€ ton [2]
(Jacobsen et al. 2017)	Bio-based fertiliser	50% of price of mineral fertiliser	Class 2 farmers "old and not interested"	The cost of application of slurry is 1,34€/ ton and with 5 kg N per

	Bio-product 1: [4] Granulate, x7 volume of mineral fertiliser, 10% uncertainty in N content, with organic carbon	8% of price of mineral fertiliser Will not pay	Class 1 farmers "Young and interested" Class 2 farmers "old and not interested"	ton which is around 0,27€/ kg N. Application of mineral fertiliser is around 0,15€/kg N/ton.
	Bio-product 2: Granulate, x4 volume of mineral fertiliser, 5% uncertainty in N content, with organic carbon	34% of price of mineral fertiliser Will not pay	Class 1 farmers "Young and interested" Class 2 farmers "old and not interested"	
	Bio-product 3: Granulate, same volume as mineral fertiliser, no uncertainty in N content, with organic carbon and fast release of nutrients	51% of price of mineral fertiliser 27% of price of mineral fertiliser without fast release of nutrients 40% of price of mineral fertiliser with fast release of nutrients	Class 1 farmers "Young and interested" Class 2 farmers "old and not interested"	
(Power et al. 2019)	Recycling-derived fertiliser	Free of charge Same price of mineral fertiliser Same price or 80% of price of mineral fertiliser 50-80% of price of mineral fertiliser <50% of price of mineral fertiliser	18% 17% 19% 23% 14% Of 691 respondents	
(Tur-Cardona et al. 2015)	Solid form Presence of organic carbon Hygienisation Fast release of nutrients	18% of price of mineral fertiliser 28% of price of mineral fertiliser 20% of price of mineral fertiliser 11% of price of mineral fertiliser	Flemish farmers (Belgium)	
(Tur-Cardona et al. 2018)	Solid fertiliser Organic carbon Hygienic Fast nutrient release	44% of price of mineral fertiliser 39% of price of mineral fertiliser 31% of price of mineral fertiliser 52% of price of mineral fertiliser 17% of price of mineral fertiliser 35% of price of mineral fertiliser 42% of price of mineral fertiliser 30% of price of mineral fertiliser 18% of price of mineral fertiliser 22% of price of mineral fertiliser	Benelux Denmark Hungary and Croatia Benelux Denmark France and Germany Benelux Denmark France and Germany Benelux	

Table 4-5. Indicative values mineral fertilising companies are willing to pay for recovered nutrient products.

Reference	Product	Suggested price
(Notenboom et al. 2017)	Struvite from wastewater treatment in the Netherlands	65€/ton Excl. transport cost
(Ceulemans and Schiettecatte 2013)	Struvite from wastewater treatment in Belgium	50-90€/ton
(NuReSys, Waregem, BE, personal communication 2013)	Struvite from wastewater treatment in Belgium	45€/ton
(Bolzonella et al. 2017)	ammonium sulphate (6% N, 30% ammonium sulphate)	30 €/m^3
(Dikov et al. 2014).	P-salt product that more or less meets with the quality requirements of the company	Same price as phosphate rock i.e. 176-327€/tonne P2O5)
(Bussink and van Dijk 2011a)	struvite	½ to 2/3 of price TSP
(VCM and Fraunhofer IGB 2015)	P-salt	50€/ton
Pilot Mineral concentrates NL **2009** **2010**	Mineral concentrates Price payed by farmers	 1,25€/ton 1,19€/ton
Personal communication SYSTEMIC plant, 2018	Ammonium sulphate solution	10-25€/ton

4.6 Performance

Detailed information on the performance of the recovered nutrient products from digestate, produced within the SYSTEMIC project, can be found in "D 1.13. Final document on product characteristics, lab results and field trials". This report will be available on the SYSTEMIC website and after the project on the websites of the SYSTEMIC consortium[3])

[3] https://www.wur.nl/en/Library.htm; https://www.biorefine.eu/; https://www.vcm-mestverwerking.be/en/faq/3921/systemic

5 Market strategy

Before entailing in nutrient recovery from digestate, one has to figure out first which recovered nutrient products would have a demand in the region (Chapter 2). If there is no demand yet, the marketing strategy, including the communication and advertising has to be very convincing towards the target buyer group. Therefore, a good marketing strategy is the key to greater public acceptance and higher profit margins.

Since technology suppliers typically do not care for the marketing of the products produced by their systems (only exception is Ostara, see ANNEX III.4), the recycled nutrient producer will have to market his own products. The optimal marketing strategy will depend on the buyer group that is chosen, and which assets and specifications of the product are preferred by the buyer group (Table 5-1).

Table 5-1 Overview of target buyer groups, corresponding marketing level and preferred quantity and product composition.

Target buyer group	**Marketing level**	**Purchased quantity**	**Specific composition**
Farmers and horticulturalists[1]	Directly at the producer wholesaler	Large	++ Products that meet specific crop demand
Mineral fertiliser producers or chemical producing industries [1]	Directly at the producer	Large-medium	+++ Products with high purity
Traders in recycled products [1]	Directly at the producer	Large-medium	- Quality less important
Retailers, wholesalers, garden centres[2]	Directly at the producer	Large, but also variety of packages sizes	++ high variety of different products
Serious hobby gardeners [1]	specialized horticultural businesses or garden centres	Small	+++ products perceived to be of premium quality (i.e. premium brands)
Price sensitive or less engaged gardeners[3]	grocery stores, supermarkets, do-it-yourself stores or online direct at the producer	Small	+ General purpose fertilisers or soil improvers

1 Chapter 4

2 (Dahlin et al. 2015)

3 (Dahlin et al. 2016, 2017)

5.1 Communication, Promotion and Advertising Strategy

In general, a good promotion and advertising strategy will have a huge impact on the profit margin. For this, one needs to maximally respond to the preferences, social environment and even emotional triggers of the chosen target buyer group. Emotions and sentiment are the biggest driver of purchases: use a personal approach like giving away free samples to the local garden club, getting testimonials from farmers or known and respected people, creating a story behind the creation or producer of the product that people can relate to, etc.

It is beneficial to emphasize in communication and advertising the **pro-environmental effects** of the recovered nutrient products. The fact that a farmer will be reusing nutrients when buying the product, will boosts their environmental conscience, knowing they are not importing nutrients by means of mineral fertilisers (de Hoop et al. 2011).
Home gardeners are more emotionally triggered when it is mentioned that by using the products, they help to preserve endangered peatlands (Dewaelheyns et al. 2013; Dewaelheyns, Rogge, and Gulinck 2014).
Representatives of the NPK-industry are aware that primary elements (like P) are finite and that the demand for more sustainable fertilising products is growing due to a rising environmental awareness of the consumers.

For farmers it is important to mention that some recovered nutrient products contain **organic matter and valuable micro / trace elements**, in the absence of contaminants and pathogens and odour. Improvement of the soil structure by adding organic matter is the most important reason for farmers to use organic fertilisers (Case et al. 2017; Tur-Cardona et al. 2015).
For home gardeners, the advantage organic products offer as the ultimate slow-release fertilisers should be highlighted. Meaning that with the use of these fertilisers, it is very difficult for gardeners to over fertilize (and harm) their plants, which often happens in private gardens (Dewaelheyns et al. 2013, 2014).

Farmers and mineral fertiliser producers usually buy products in large quantities, so for this target buyer groups, **packaging** is less relevant.
However, for retailers and home gardeners the package design is a vital element influencing their consumer behaviour because the product itself provides few visual cues to influence consumer purchases. A survey of consumer preferences concluded that women are the principal purchasers for fertilisers or soil improvers for the cultivation of flowers and vegetables. In this case, appealing packaging could illustrate the outcome gardeners expect after using the product: e.g. bright blooming flowers and large tasty-looking vegetables (Dahlin et al. 2017). On the other hand, men frequently are instructed to buy the products in larger volumes that are heavy to carry (Dahlin et al. 2017). Packaging these products in bags provides producers a low-cost alternative to for example cardboard boxes and also has the advantage of allowing easy imprinting. Including handles, can make the bags more user-friendly and making them from recycled paper, adds to the packaged product's environmental appeal. Re-usable plastic buckets are another eco-and user-friendly alternative.
The details about nutrient composition and information about product use, need to appear on the packaging. This will help the end user to choose the right product. Many end users are unaware of the composition of soil amendments and fertilisers and this makes it difficult for them to assess the quality of a new product, making pre-sales services and advertising very important (Dahlin et al. 2015). Gardeners simply want a well-proven product that works and are not generally concerned to ask questions regarding the product's origin. Therefore, having a product package that simply states "from organic raw materials" works best (Dahlin et al. 2016, 2017). Nonetheless, some have a general resistance to biogas resulting from public discussions about the excessive cultivation of maize for fuel; second, consumers' concerns about product impurities such as inert foreign materials. Therefore, it is better not to mention that they are derived from biogas plants.

In general, it is best to not draw too much attention on the product's shortcomings compared to mineral fertilisers. If a certain product quality, form or performance cannot be obtained, it is better to highlight other aspects of your product or suggest solutions for the shortcomings in the advertising.

A **product name** is not necessary when targeting farmers and mineral fertiliser producers, yet in general it does differentiate from other products and creates a sign of recognition that lingers.
A good product name for appealing to home gardeners relates to the properties or application of the product. They ultimately link the brand name to a certain quality and reputation, which needs to be built.

A well-designed **website** provides the consumers a good overview of the available products and information on where and how to obtain them.

5.2 Direct contact with end users

By getting in direct contact with the target buyer group and entering their social environment, one can create a buyer experience that lasts longer and builds trust. For example, hosting open days with guided tour on the production plant, live demonstrations of field trials and application of your products, giving away free samples, ….These efforts can result in articles in local newspapers and agricultural journals which function as are free advertising.

If a third party is needed for the sale of the products, it is best to rely on qualified, **trustworthy personnel**. This way a recovered product producer can stay in control of the information that is given to the costumers, especially to farmers. Home gardeners also prefer distribution through a reputable or known retailer.

When dealing with farmers, higher chances of selling the recovered product can be achieved when one is able to **communicate correct information** about the legal status, application limitations, trade regulations of the recovered products. For both farmers and home gardeners, helping to **choose the right product** also builds trust in the product and the provider. This can include:

- which product best fills in the nutrient need, and if a certain amount of fertiliser can be eliminated because of this,
- finetune the specific fertilisation strategy to avoid over-fertilisation or deficiencies,
- calculate how much money can be saved by replacing mineral fertilisers and making more space for manure,
- calculate how much money can be saved in application cost (using a contractor or own equipment) and storage,
- which form of fertiliser best fits the user's soil structure.

These are complex calculation exercises for which most biogas plant owners don't have the experience nor the time. Research facilities or agricultural consultants can be approached for support.

Mineral fertiliser producers will have specific requirements for recovered nutrient products to be able to use it as a secondary raw material in their process (see Chapter 4). Convincing them of the value of the product will include technical discussions and price negotiation, which is best done by the recovered product producer themselves, without an intermediate party.

5.3 Extra actions that will boost the products' marketability

Most recovered nutrient products are relatively new, and many farmers are therefore unaware of their existence or have heard about them but don't see their value (yet). This was confirmed by a survey done in North-West Europe. Respectively 5%, 15% and 20% of the 865 respondents had heard of respectively

struvite, mineral concentrates and scrubber waters (Power et al. 2019). In their fertilisation methods, farmers are creatures of habit. Frequently, they will only use a new product if they can see it and witness the positive effects on their crop yield and quality.
Therefore, **showing the product's performance** compared to raw manure or mineral fertilisers might be able to persuade them. Universities and research facilities can be approached to set up scientifically reviewed field trials. Also, farmers can be approached who would like to use the product and demonstrate and testify on the results. If the outcome is good, this will aid to invalidate the prejudices about the recovered nutrient product. These results can then be used as informative advertising and will help buyers evaluate products that for the most part they do not fully understand.

The **environmental benefit (Life Cycle Analysis)** can be quantitatively determined and used to emphasize the sustainability and potential in circular economy of the products. This is the main advantage that recovered product have over mineral fertilisers. The consumer's attention for these aspects is growing, even in fertiliser producing companies. Again universities, research facilities, coordination platforms and agricultural consultants can be approached for information and support.

Investigating if a cheap, effective, easy in use and low-emission **application technology** can be coupled to certain products can create an extra added value for consumers. If possible, the recovered product producer can provide the application service and equipment himself, hereby gaining extra profit and costumer reliance. If not, a good relation and agreement with a contractor can be established to do this.

Also, **other related services and products** can be provided, like storage, training on application, green electricity, process water, irrigation water, pure water or heat and CO_2 to greenhouse growers. Providing other things next to the product helps to build a sustainable, trustworthy relationship with clients and creates a total package experience.

Many farmers have experienced deficiencies or nutrient surplus by using manure or mineral fertiliser. Creating **products with a tailor-made composition** provides an answer to this issue and differentiate the products in the market and add to their competitiveness. By blending different recovered nutrient products, the required nutrient concentrations and ratios could be achieved. This way, different specialized fertilisers are created, which are appealing form farmers but especially for gardeners and retailers (Table 5-1).

To get recovered products to enter the fertiliser market and compete on the same level as mineral fertilisers, they will first have to get acknowledged to be **applied as a mineral fertiliser**. The use of processed manure/digestate products under the same conditions as mineral fertilisers in nitrate vulnerable zones could be a major contributor for the feasibility of business cases of NRR in Europe. The creation of a market for the end-products of NRR techniques has a great impact on the financial viability of these investments.

On national level it is possible to ask for a derogation (See ANNEX III.5 as example). In the framework of a project, an individual exemption from the application limit can be obtained by the regional or national ministry, limited in time and space, product, user.
This is also possible to file a group exemption on a larger scale, but still limited in time. This is not per se in the framework of a project (see Pilots in the Netherlands and SAFEMANURE on European level).
A group of producers, each producing different products can contribute to a file to build their case for the European Commission. This should contain the description of the process, product characteristics, area on which the products would be applied, projects that could include and finance field trials.
A research centre should be involved to assure report on the field trials and independent organisation should be appointed to assess and monitor the product quality and monitor the number of products that is are applied. This is a time-consuming process for which biogas plants need the support of national sector organisations and research institutions.

When attempting to sell the recovered nutrient products to a mineral fertiliser producer, it would be beneficial for both parties if a collaboration is designed that **integrates the logistics of products** from and to the location of the mineral fertiliser producer. Find a way to streamline storage and supply of chemicals to the biogas plant and recovered nutrient products to the fertiliser producer in a cost-efficient way. Also, if large volumes of the product are required, this can be achieved by establishing joint ventures with other biogas plants. This is a complex cost-benefit analysis for which most biogas plant owners don't have the experience nor the time and therefore will need to approach universities, research facilities, coordination platforms, agricultural consultants. A good example can be read in ANNEX III.1.

Niche markets (see ANNEX II) mostly require products with very specific characterisation and are frequently still in development. Entering these markets usually takes a lot of research, testing, finetuning of product, logistics, negotiating, etc. but can eventually render much higher profit margins and encounters less competition. This is a time-, money- and energy consuming process for which most biogas plants don't have the resources nor are experienced for. Entering these niche markets will need the support of universities, research facilities, consultants, private corporations, funding etc.

An alternative, to alleviate biogas plants from the money- and energy consuming marketing process, is to create an independent (non-profit) organization, company, project or joint venture on national level or EU level that:

- Includes or has good relationship with people from the complete chain of stakeholders:
  - feedstock suppliers (animal farmers, food industry, etc.),
  - provinces (for permits and allocation of plants),
  - governmental institutes, agricultural consultants, agricultural organizations, universities, labs (for independent, reliable information on performance, safety, composition and legislation of the products)
  - retailers, mineral fertiliser producers, industry,
  - biogas plants producing recovered nutrient products.
- Helps to choose the right recovered nutrient product for the demand of each end user.
- Does public relations for the different products of the biogas plants.
- Gets technology providers to develop user friendly (and preferable cheap) equipment for farmers to apply these new fertilisers.
- Buys, rents and leases user friendly application equipment best fitted for each recovered product.
- Motivates technology companies to engage in product sales and marketing – the Ostara business model is a good example, but it needs quite a high initial investment which seems to be difficult to cover.
- Functions as independent trading platform for feedstocks and contractor services.
- Negotiates with mineral fertiliser companies, industries and retailers.
- Establishes sustainable logistic chains to end users.
- Makes an evaluation of the regional NRR pilots with regard to the economic feasibility and environmental aspects and informs biogas plants on the developments.
- And above all, is trusted by Biogas plant owners it works for.

5.4 Conclusions

Geography appears to be a key driver of pricing for recovered nutrient products since transportation costs, especially those associated with liquid products, increase substantially as distance increases. Therefore, **sound logistics planning and management** are vital for the profitability of NRR.

Also, one needs to be aware that creating one very marketable product, could produce a few other less marketable (by-)products, that could shift the business case to negative. Therefore, **all products need to be taken into consideration** when developing a market strategy and a sustainable, profitable balance needs to be created, selling or disposing all the produced products.

When eventually a biogas plant achieves to create a positive market value for all the produced end products, this will not automatically make a positive business case.
The **total picture** of getting feedstock, implantation and running of the digestate treatment technologies, the disposal of all side streams or by-products, in combination with the production of biogas, needs to be in balance to get to a profitable business case.
Nonetheless, the disposal or marketing of digestate products is a Key Performance Indicator in the business case of a biogas plant (see SYSTEMIC D.2.2 Business case evaluation report). In general, biogas plants currently underestimate the impact of a good marketing strategy and should make greater efforts to better understand and respond to consumer preferences and concerns and develop effective and long-term marketing strategies for recovered nutrient products.

Yet, many of the suggested actions in the market strategies (Chapter 5) will often exceed the staff capacity, experience, available time and budget of biogas plants, which are mostly SME's already preoccupied with their core business: producing biogas.
However, if the recovered products qualify as a good alternative fertiliser or secondary raw material, mineral fertiliser producers are sure that they could create a market for this in a short time notice. In this case the biogas plant will not need to invest in advertising, promotion and communication themselves.

The lack of marketing power of smaller biogas plants could be eliminated by establishing a regional co-operation of biogas plants. This could lead to shared marketing costs, shared investment capital, and reduced risk. Larger cooperatives would also enjoy an improved negotiating position with larger purchasers.

6 Outreach Locations

This chapter provides the prospects of marketing products from digestate for each Outreach Location region. The end products produced, and technologies installed by the Outreach Locations can be found in Table 1-1.
In the Living Lab meeting in 2020, the Outreach Locations will be able to test the trial version of the "NRR calculation tool for cost-benefit analysis, product estimation and technology selection": NUTRICAS. Together with the consortium, these outcomes will be used to take the first steps in exploring possibilities to better market their current products or produce more commercially interesting or demand driven products.

6.1 Biogas Bree and Waterleau New Energy, Flanders, Belgium

Both Flemish Outreach Locations (Biogas Bree and Waterleau New Energy) are located in a region with a surplus amount of manure due to intensive livestock farming and experience a growing competition for application of digestate with manure and digestate form other neighbouring anaerobic digestion plants. Phosphorus is typically the first limiting factor when fertilising in Flanders with manure products followed by limitation due to the N content of manure products (Figure 2-1 and *Figure 2-3*). In addition, manure (derived products) are not allowed to be used in Wallonia. Consequently, digestate has a negative price when used as fertiliser in the region of the plants.
In the Flanders, all crops discussed in Chapter 2 contribute to a relatively high share of the utilised agricultural area. For the regions near Biogas Bree (±100km),cereals, maize and grassland cover a substantial amount of the agricultural land (Table 6-1). For these crops ammonium sulphate, NK concentrates or liquid fraction from digestate could be interesting alternative fertilisers (Chapter 2).
In the region of North France, close to Waterleau New Energy, especially cereals and root crops are dominant. Next to scrubber salts and NPK concentrates, also solid fraction of digestate or struvite could be used to complete the nutrient demand of these crops.
However, when transporting liquid products (in large volumes), on has to strive to keep the transport distance has to a minimum to reduce costs and CO_2 emissions.
Plant owners can also focus on other markets, which are described below.

Table 6-1 Crops percentage (%) of UAA(utilised agricultural area: cropland + grassland) in the region of Biogas Bree and Waterleau New Energy(Eurostat: Land cover overview by NUTS 2 regions, type of land-cover % of UAA, 2015)

			Region Biogas Bree				**Region Waterleau New Energy**	
	Flanders (BE)	**Limburg (BE)**	**Northrhein-Westfalen (DE)**	**Region Köln (DE)**	**Zuid-Nederland (NL)**	**Limburg (NL)**	**West-Flanders (BE)**	**Nord-Pas-de-Calais (FR)**
Grassland	47,7	44,1	42,1	51,1	50,0	49,4	42,8	31,3
Cereals	30,1		44,3		28,7			47,4
Maize	20,4		17,4		21,7			9,0
Potatoes	4,3		1,7		6,5			6,0
Sugar beet	2,5		3,5		2,9			5,5

1. RENURE products

Criteria are now being developed to allow the use of RENURE (REcovered Nitrogen from manuRE) products in Nitrates Vulnerable Zones above the threshold established by the Nitrates Directive (i.e. 170 kg N ha^{-1} .$year^{-1}$) (91/676/EEC). In Flanders, ammonium sulphate produced by acid air scrubbing can be applied above the application limit of 170 kg N /ha^{-1} /$year^{-1}$. Nevertheless, marketing of such RENURE products is still challenging because farmers are not used to pay for fertilisers produced from manure and because costs for storage and field application of RENURE products are typically higher than for synthetic N fertilisers. Also, the acid pH of ammonium sulphate makes farmers more reluctant to use this product. Biogas Bree has therefore improved their acid air washing system in a way that it can produce ammonium sulphate with neutral pH. They are also investing in improving the image of ammonium sulphate as alternative for mineral N fertilisers with the UNIR project ("Vlaanderen circular grant"). The potential of crystallizing ammonium sulphate and selling it to industry, could be looked into, though this is technically still a challenge. Producing ammonium sulphate could also be an alternative for Waterleau New Energy when the market for the ammonium water is saturated.

2. Niche markets outside agriculture

Waterleau New Energy produces ammonia water which is sold to an incineration plant for DeNOx of their exhaust gasses (ANNEX II.6.3). However, the market for ammonia water is limited and more biogas plants are producing this product, sometimes of better quality. Increasing the N content of the ammonia water from 10 to 20% through investment in an advanced evaporation and ammonium stripping unit could create a competitive advantage through a reduction of costs. Yet, treatment of exhaust gasses remains a niche market and Waterleau is therefore advised to also explore opportunities to valorise N as a RENURE product.

3. Tailor made fertilisers for export

Both plants produce dried granular fertiliser from the solid fraction of the digestate. These products typically have a high P:N ratio that does not meet crop demand. Producing granular fertiliser with custom-specific N:P:K ratio will give them an advantage in the market for dried organic fertiliser.
fertilizer. Biogas Bree already decided to invest advanced dryers which enables them to blend solid fraction and N-rich liquid fraction or ammonium sulphate into a tailor-made fertiliser. Such a tailor -made granular product can be sold to retailers or individuals as garden fertiliser against high prices but are also suitable for export to e.g. France.
Since phosphorus limits are always the first ones met when fertilising in Flanders with manure products, creating a P poor solid fraction and P fertiliser, following the example of Groot Zevert Vergisting in The Netherlands, could also be an option. However, both plants have already invested in advanced dryers and have sufficient amount of thermal heat available implying that an investment in a P stripper may not be economically justifiable.

6.2 Ferme du Faascht-SCRL Kessler, Wallonia, Belgium

Kessler is located in the south of Wallonia which has a high livestock density. The region is however not designated as a nitrate vulnerable zone (Figure 6-1) and Kessler is therefore still able to dispose most of its liquid N-rich fraction on his own fields or on their partners farms in a radius of 10 km. The Kessler biogas plant mostly treats manure from his own farm. Phosphorus is a however a limiting factor in applying manure (*Figure 2-3*).
The predominant crops in the region are grassland, cereals and maize (Table 6-2). Scrubber salts, liquid fraction of digestate, NK concentrate, and solid fraction could be useful fertilising products for these crops, able to fill the nutrient gap from basis fertilisation with manure.

Kessler has already found a niche market for part of their dried solid fraction of digestate. Test have been running where this product is used as fertiliser in greenhouses for cultivation of tomatoes. In 2021, the building of their own greenhouse for tomato cultivation will be executed. The remaining part of the solid P rich digestate is used on their own land.

Kessler is already searching for alternatives in case their region in Wallonia is to become a nitrate vulnerable zone in the future. They focus therefore on technologies to reduce the N content by e.g. biological treatment but investment in production of NK concentrates complying with RENURE criteria would be a more sustainable option. Production of NK concentrates is likely also economically feasible considering the fact that Kessler has sufficient storage capacity on-site and would be able to apply NK concentrate on his land or in Luxembourg if a derogation is approved.

Figure 6-1 Nitrate Vulnerable Zones in Wallonia. Source :www.rochefort.be

Table 6-2 Crops percentage (%) of UAA(utilised agricultural area: cropland + grassland) in the region of SCRL Kessler (Eurostat: Land cover overview by NUTS 2 regions, type of landcover % of UAA, 2015)

	Wallonia (BE)	**Luxembourg (BE)**	**Luxembourg (LU)**	**Est (FR)**	**Lorraine (FR)**	**Campagne-Ardenne (FR)**
Grassland	56,0	79,6	55,4	53,8	47,0	26,8
Cereals	28,5		33,7	33,1		
Maize	6,3		6,9	11,6		
Potatoes	4,4			0,3		
Sugar beet	3,4			0,3		

6.3 Waternet and GMB, The Netherlands

Both Waternet and GMB produce digestate from sewage sludge.
The digestate from GMB originates from source-separated treatment of non-polluted streams such as food-waste but is mixed with sewage sludge before separation in a centrifuge.
Currently, the solid fraction of the digestate is incinerated because it can contain besides a lot of nutrients and organic matter also heavy metals, pharmaceuticals, hormonally active substances, persistent organic pollutants, etc. Dutch and European (waste) legislation and risk perception of customers and consumers prevents direct use of this end-product.

Further extraction of nitrogen (ammonia stripping-scrubbing) and phosphorus (P-precipitation) could close the nutrient cycles. Scrubber salts have proven to be equally performing as mineral N fertilisers with heavy metal contents below the limit values for N fertilisers indicated in the Fertilising Products Regulation (EU/2019/1009) (Huygens et al. 2019). GMB is already using the produced ammonium sulphate as a fertiliser in agriculture.

At Waternet struvite is recovered from the digestate and is sold to ICL Fertilisers as secondary raw material for phosphorus fertilisers. Currently only 20% of the total phosphorus present in the digestate can be recovered as struvite. Waternet has the ambition to increase the amount of recovered phosphorus substantially.

6.4 Bojana, Croatia

Bojana is located in a region with intensive livestock farming. They treat cattle manure and agro-industrial waste. The digestate of Bojana biogas plant is separated and the solid fraction is mixed with straw and reused as bedding material for the cows. This is an important synergy for the surrounding farms to avoid the cost of straw. The liquid fraction is spread on the land as alternative for mineral fertiliser. The transport is maximum 50 km on the road, 25 km in a circle around the farm. Therefore, Bojana has already a circular business case.
Bojana is not located in a nitrate vulnerable zone and has therefore no problem to dispose of their digestate as such in the area. However, Bojana is looking into opportunities to increase the value of their digestate and make use of the residual heat.

Farmers in this region use several types of mineral fertilisers during the plant season, including NPK 0-20-30, NPK 7-20-30, NPK 15-15-15, UREA (45 % N) and CAN (27 %). When choosing fertilisers, Croatian farmers pay a lot of attention to the price of product, but also don´t ignore the content of the fertiliser (amount of nutrients).
Ideally, the air from the lagoon should be cleaned with an acid air scrubber or the digestate itself could be stripped and scrubbed from ammonia, recovering the nitrogen as ammonium sulphate or nitrate and creating an odour free digestate. Ammonium sulphate is a good fertiliser for filling in the nitrogen demand of grass, maize and cereals, the main cultivated crops in the region (Table 6-3).
However, Bojana has currently no interest in production of ammonium sulphate or ammonium nitrate or ammonia water because of the high investments needed to produce such products. Yet, these products could prove also useful to blend with solid fraction and create a dried product. Bojana, already has residual heat available for drying. Solid, tailor-made products approach better the crops needs, can cut transport costs due to lower volumes and are easy to apply by a farmer. Such products could therefore have a positive marketing value.
Alternatively, also production of NK concentrates could be an option though an economic assessment is needed to quantify the benefits of such an investment.

Table 6-3 Crops percentage (%) of UAA(utilised agricultural area: cropland + grassland) in the region of Bojana (Eurostat: Land cover overview by NUTS 2 regions, type of landcover % of UAA, 2015)

	Region Kontinentalna Hrvatska
Grassland	42,5
Cereals	25,7
Maize	13,5
Potatoes	0,3
Sugar beet	0,5

6.5 Emeraude Bioénergie-Cooperl, France

The region is characterised with intensive pig husbandry, creating a manure surplus. The biogas plant Emeraude Bioenergie already has developed a circular system accepting this manure, together with slaughterhouse waste from the neighbouring slaughterhouse. Fertival, part of the Cooperl group and located next to the biogas plant, dries the digestate and sells it as organic fertiliser.
Yet, Emeraude still has an unvalorised end-product, namely the ammonium sulphate. This could be commercialized to farmers as alternative to mineral N fertiliser or used to make specialized blends.

6.6 Greengas AD, Ireland

All of the digestate produced by Greengas AD is used on farmland controlled by the plant. Currently, this is enough but when the plant would wish to expand, more outlets will be needed for the digestate. Ireland's agricultural land is mainly grassland, and some cereal cultivation (Table 6-4). For grassland, having high N, K and sulphur needs, ammonium sulphate is the ideal fertiliser (Chapter 2). The region of Greengas AD is located in an area with possible sulphur deficiency (Figure 6-2). On S deficient soils, it is advised to apply 20 kg/ha per year for grazed swards and for silage swards on S deficient soils, apply 20 kg/ha of S per cut (Teagasc et al. 2016).

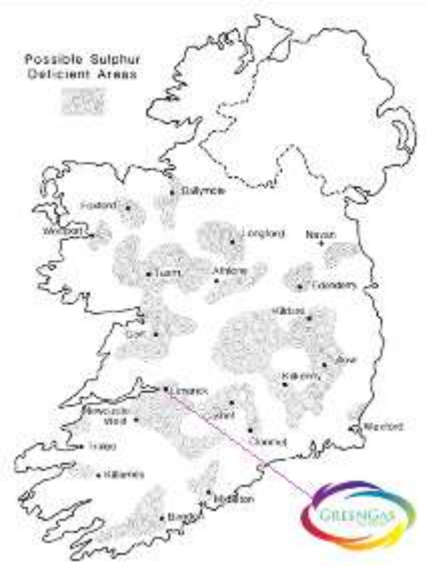


Figure 6-2 Areas in Ireland that are possibly deficient in Sulphur (Teagasc et al. 2016)

The Irish farmers are reluctant towards unfamiliar products (e.g. compost) and this will probably be the same for digestate, scrubber salts, mineral concentrates etc. Yet, with demonstration of application, results on crop yield and quality and a reasonable price setting they will probably embrace it as fertiliser. However, they prefer low volumes with a high concentration of nutrients.
Greengas AD is therefore interested in ways to reduce the moisture content of the digestate. (Bio)thermal drying, using residual heat from the digester, could be interesting in their case. Mixing with ammonium sulphate could help create a N:P:K:S ratio more in line with the crop needs.

Table 6-4 Crops percentage of UAA(utilised agricultural area: cropland + grassland) in the region of Greengas AD (Eurostat: Land cover overview by NUTS 2 regions, type of landcover % of UAA, 2015)

	Southern and Eastern Ireland
Grassland	87,7
Cereals	6,8
Maize	0,3,
Potatoes	0,2
Sugar beet	0,1

6.7 Makassar- Somenergia, Catalonia, Spain

Digestate has no (negative or positive) value in Spain and the land to spread the digestate on in the area is limited. Since there are no subsidies for biogas in Spain, the biogas plant cannot make large investments in expensive nutrient recovery technologies.
Separation of the digestate by means of a centrifuge is a simple way to introduce nutrient recovery. Ammonia losses could be reduced by covering the digestate lagoon, installing air washers and learning more about low NH_3 emission application techniques.

6.8 Atria, Finland

Atria Biogas and NRR Plant project is located in Seinäjoki, a region characterized by intensive primary production and has a higher P soil status (region of 100km radius) than the rest of the country (*Figure 2-3*). The general P limit in Finland is 32 kg P/ha and Finland is a Nitrogen Vulnerable Zone.
In Finland, growing season is quite short. There are only <2 months per year when the digestate spreading makes sense, since spreading into frozen land is not allowed nor useful. The rest of the year, the produced digestate has to be stored, which requires a very large storing capacity.
The biogas plant will be located close to Atria's slaughterhouses, and is designed to make optimal use of energy and manure (as a resource) to not be hindered by the legal constraints.

The digestate treated with the NRR process will be transformed into solid fraction digestate and NPK concentrate and water. Part of the NPK-concentrate can be mixed with the solid fraction to improve the fertiliser properties of solid fraction. Both products will be transported economically into areas where nutrients are really needed. One of key aspects of the Atria business case it the production of LBG, a "green" fuel that will partly be used for the trucks delivering the manure and disposing the nutrient products. The largest part of the LBG will be purchased by other customers. Atria will produce an amount of LBG which is comparable to 10 million litres of diesel.
By producing clean water, <50% of the incoming material amount needs to be stored and transported. Approximately 200 m3 of water will become available for recycling and discharging on site, the amount of water doesn't have to be transported as diluted digestate or treated as waste water.

The plant is estimated to produce ±50.000 tons of solid fraction per year. This relates to 418 tons of P/year and due to these large volumes it could be economically feasible to recover this as phosphorus salts with the a P stripping system with acidification. For struvite precipitation, the concentration of phosphorus is relatively low (1,9 kg P/ton) and most phosphorus will be organically bound and therefore not available for precipitation. The remaining solid fraction, low in P, could be a valuable soil improver.

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I. ANNEX I Product characteristics

Detailed information on the product specific technology description, characteristics and composition, agronomic effectivity and risk assessment for raw digestate, liquid fraction of digestate, ammonium sulphate, ammonium nitrate, ammonia water and mineral concentrates after membrane technology can be found in the report "Nitrogen fertilising products based on manure and organic residues"(Ehlert et al. 2019)[4].
The other products mentioned in this report are described in the following paragraphs.
More information on the characteristics of the products produced by the SYSTEMIC demo plants can be found in "D 1.13. Final document on product characteristics, lab results and field trials"[5] and "D1.15 Full report on environmental impact assessment of recovered products".

I.1 Dried and pelletized (solid fraction of) digestate

The composition of digestate is mainly determined by the feedstock that is digested. In general, it can be concluded that the solid fraction of digestate contains the largest amount of the solids and organic matter, and phosphorus, which is mostly bound to the organic matter.

The nutrients can be more concentrated by drying the (solid fraction) of digestate. The final dry matter content depends on the type of dryer, residence time and temperature.
Table I1. illustrates this by showing analysis results of different types of technology trains and digestates. Solid fraction after drying, can be regarded as "sanitized", when it has been treated at least 70°C for 60 minutes in an approved biogas, composting or technical plant.

This is important to comply with when trading the product in Member States and is applicable for digestate from co-digestion with manure or other animal by-products (Category II, art. 9 of 1069/2009/EC) and all derived products from this.

Other processes or technology trains treating the digestate for example at lower temperatures for a longer period, can be individually acknowledged as "sanitation methods" when the process kills a minimal number of pathogenic micro-organisms. For this, a certified company, has to examine the process and products and set measurements or control points (EC 142/1 2011 Annex 2, Chapter 3, part 2).

[4] available on www.wur.nl/environmental-research
go to "Publications" – "Wageningen Environmental Research reports"
[5] https://www.wur.nl/en/Library.htm
https://www.biorefine.eu/
https://www.vcm-mestverwerking.be/en/faq/3921/systemic

Table I-1. Examples of dried/pelletized/solid fraction of digestate.

	Solid fraction (Screw press) [1]	Solid fraction (N stripper + DAF +squeezer) [2]	Dried solid fraction (centrifuge + DAF) [3]	Dried solid fraction (centrifuge) [4]	Dried solid fraction (Centrifuge) [5]	Dried solid fraction (centrifuge) [6]	Dried digestate [7]	Dried digestate [8]
Dry Matter %	25,8	42,4	91,2	85	95	90	92	27,2
Organic Matter %			52,3					
N-total (g/kg)	8,7	9,9	31	21	3	2,7	20	7,4
NH4-N (g/kg)	4,4	4,9	0,88					
P-total (g/kg)	2,2	2,4	19	46	5	1,5	35	10,8
K-total (g/kg)	5,6	6,4	11	26	13	2	43	3,8

[1] Solid fraction of digestate from chicken manure and corn after screw press (Benas, Germany)

[2] solid fraction of digestate from chicken manure after N stripping, DAF and squeezer press (DVO biogas plant, USA)

[3] Dried solid fraction of digestate from food waste after centrifuge and DAF (AMPower, Belgium)

[4] Dried solid fraction of digestate from slaughterhouse waste water and solid pig manure after centrifuge (Emeraude Bio-énergie, France)

[5] Dried solid fraction of digestate from food -and agricultural waste after centrifuge (Waterleau New Energy, Belgium)

[6] Dried solid fraction of digestate from cattle slurry, dairy and agricultural waste after centrifuge (Biogastur, Spain)

[7] Dried digestate from pig manure (Biogas Bree, Belgium)

[8] Dried digestate from cattle slurry and food industry waste (SCRL Kessler, Belgium)

Some biogas plant managers or manure processors go even further in nutrient refinery by extracting the phosphorus from the (solid fraction) of digestate and obtaining an organic soil conditioner low in P and N and with a more favourable N/P ratio (ANNEX III.6). Process and technology description can be found in "D 3.2. Scenario's and schemes of proven NRR techniques".

Table I-2.Examples of P-poor solid fraction after acidification.

	acidification of raw digestate + separation [1]	acidification of solid fraction of digestate [2]
DM%		32
OM%		28,5
N-total (g/kg)		5
NH4-N (g/kg)	3.2	
P2O5-total (g/kg)	3.4	3,2
K2O (g/kg)		0,2

[1] Solid fraction of digestate from co-digestion after acidification and centrifuge(VCM and Fraunhofer IGB 2015)

[2] Solid fraction of digestate from co-digestion after centrifuge and acidification (Groot Zevert Vergisting, The Netherlands)

Due to the fertiliser value of digestate but, at the same time, the impossibility to meet always the requirement in the surrounding production areas, some authors propose the transformation into solid form (granules) to be easily stored and transported with benefits in economic and environmental terms (Cotabarren et al. 2019).

In addition, the possibility of adapting the properties of the solid product to give proper nutrient release profiles would reduce the leaching problem associated with the direct application of liquid fertiliser.

I.2 P-salts & Struvite

Struvite ($MgNH_4PO_4.6H_2O$, magnesium ammonium phosphate) and other phosphorus salts are currently recovered in different sectors like potato industry, wastewater treatment and manure processing. Pure struvite contains 5,7% N, 28,9% P_2O_5 and 16,0% MgO.
The plant uptake efficiency depends on how quick the struvite crystals dissolve in the soil solution. More acid soil leads to a faster breakdown of the precipitates. If there is an excess of MgO or $Mg(OH)_2$ present in the struvite, this can have a neutralizing effect on the soil acidity and slow down nutrient release.
There are other forms of struvite that have an important share of potassium (($MgKPO_4.6H_2O$).
Struvite is a slow-release fertiliser and not soluble in water or directly plant available. It is quite difficult to extract pure, carbon-free struvite from digestate (derived products) and phosphorus precipitation will frequently result in a mix of different phosphorus salts.

A poorly soluble precipitate, such as $Ca_{10}(PO_4)6(OH)_2$ or $Mg_3(PO_4)_2$ should be applied as a powder for faster nutrient release. Trials show that both magnesium and phosphate are slowly released and equally available for the crops in comparison to mineral fertilisers (Bussink and van Dijk 2011a; Ceulemans and Schiettecatte 2013). The presence of magnesium in struvite makes it very applicable for sports fields, giving the grass a bright green colour (Leenaerts 2011). Start fertilisation with struvite for corn is also possible, although it is only necessary when a soil has a low P content and/or an acid soil pH or the early spring was cold and wet.
Phosphorus in manure and digestate consists of inorganic and organic phosphorus. Inorganic phosphorus is mainly ortho-phosphate (PO_4^{3-}). Digestate from co-digestion contains 3-5 kg P_2O_5 per ton, from which 80-95% is inorganic P.
After separation, the largest share of P is present in the solid fraction, depending on the separation efficiency, as P-salts are organically bound.
The liquid fraction contains only a small fraction of the P: soluble PO_4^{3-} and suspended P.
At pH between 7-9, which is normal for digestate, most of the phosphorus will be not be dissolved but bound to the organic matter or complexed.

When Mg^{2+} or Ca^{2+} is added and alkaline conditions are generated – pH 9-10,7- P salts like struvite, K-struvite and calcium phosphate are formed that can precipitated.

To transfer the organically bound and complexed P to the liquid fraction, acid can be added before the nutrient rich stream is subjected to chemical precipitation at alkaline pH.
However, the composition and therefore also the buffer capacity of the digestate varies from digestate to digestate and this directly determines the quantity of acid needed to lower the pH (Latimer et al. 2012).

Table I-3. Examples of extracted P-salts.

	[1] acidification of raw digestate + basification + extraction	[2] acidification of solid fraction of digestate +basification+extraction	[3] basification of digestate: extracted struvite
DM%	80%	82	>90
P-PO4	12,8±0,5 % of DM	140 (g P2O5/kg)	126 (g P-total/kg)
N-total	3.6±0.6 % of DM	20 g/kg	50
N-NH4	2.8±0.1 % of DM		0
K	1.4±0.1 % of DM	5 (g/kg)	
Mg	5.1±0.2 % of DM		
Ca	6.6±0.0 % of DM		

[1] DriedD P-salts extracted from the digestate from co-digestion after acidification and centrifuge(VCM and Fraunhofer IGB 2015)

[2] Dried P-salts extracted from the solid fraction of digestate from co-digestion after centrifuge and acidification (Groot Zevert Vergisting, The Netherlands)

[3] struvite extracted from digestate of WWT sludge (Waternet, The Netherlands)

I.3 Mineral concentrate after evaporation

Concentrated digestate has a slurry-like appearance, depending on which concentration factor the evaporator can achieve, which is typically 5 -10. It is low in nitrogen and has a high conductivity, since all ammonia volatizes and ends up in the water vapour (and condensate) and all other ions stay in solution which is gradually concentrated. Table I-4 gives 2 examples of the liquid fraction of digestate before and after evaporation.

Table I-4. Examples of concentrates after evaporation

	[1] Digestate	[1] concentrate after evaporation	[2] feed	[2] concentrate after evaporation
Dry Matter % (105°C)	4,13	21,05	0,99	10,2
Conductivity µS/cm	27300		13300	1440500
Chlorides (mg/L)			1631	16000
TKN (mg/L)	4919	63025		
Nitric nitrogen (mg/L)			229	4200

[1] Liquid fraction of digestate from food waste after centrifuge and evaporator, % of concentration 66% (test) (AMPower, Belgium)

[2] Liquid fraction of digestate from food waste after screw press and evaporator, % of concentration 90% (IVVO, Belgium)

I.4 Concentrate after acidified evaporation

When acid is added to (liquid fraction of) digestate before evaporation, all nutrients including N-NH4 stay in solution and only water and some traces of volatile components transfer to the gas phase and are eventually condensed.

Table I-5 shows the results of an analysis done on ammonia water with acidification after an evaporation trial on the liquid fraction of digestate for organic biological waste. The high concentration of sulphur originates from the addition of sulfuric acid.

Table I-5: Analyses on the ammonia water from evaporation of (liquid fraction of) digestate after acidification (test Biogas Bree, Belgium)

	Ammonia water after evaporation and acidification
pH	6,8
EC (µS/cm)	92
BOD5 (mg/L)	<9
COD (mg/L)	32
Ammonium (mg NH4/L)	12
Nitrite (mg NO/L)	0,02
Nitrate (mg NO3/L)	<1
Phosphorus (mg P2O5/L)	<0,04
S (mg/L)	14
AOX (mg/L)	<0,05

I.5 Calcium carbonate

Currently, only calcium carbonate, potassium carbonate and magnesium carbonate are commonly used in agriculture (Dijkstra et al. 2012).
When ammonium-N is converted to nitrate (nitrification) in the soil, acidification takes place.
The carbonate ion helps to neutralize the soil pH at 7,5, by acting as a buffer, but the ratio of pure CaCO3 to N required is 7:1. In practice this ranges from 5,4:1 (ammonium sulphate 21%N), 1,8:1 (urea 46%N) to 0.7:1 (CAN 26%N), due to NO3- that is also taken up by plants, releasing OH- ions or volatilisation of NH3 (Fertiliser Industry Federation of Australia 2006).
As a fertiliser, calcium carbonate improves the release of the intrinsic nutrients (Ca2+) due to increasing the pH value. It also improves the biological activity and soil structure.
Calcium carbonate is almost water-insoluble and dissolves only in acid soils (up to a neutral pH range) and is plant available simultaneously.
Surplus calcium carbonate is available in the next year for prevention of soil acidification during the fertilization season. Therefore, fertilization with calcium carbonate has a long-term depot effect.

Table I-6. $Ca(CO)_3$ recovered from digestate from BENAS

	Recovered $Ca(CO)_3$
DM (%)	70-78
CaO (kg/ton)	280-370
NH4-N (kg/ton)	15-20
S (kg/ton)	18-22

I.6 Fibres

The anaerobic digestion process does not break down lignocellulose. These fibres can be extracted and refined and are applicable in fibre industries (e.g. wood, paper) only when they contain low concentrations of ammonia.
The SYSTEMIC demo plant in Germany has successfully isolated fibres from digestate with their Fibreplus® system and tested the extracted fibres in different concentrations as resource in the fibre board industry (3% bio-fibres and 10-30% bio-fibres used) and paper industry (>80% biofibres used).

Table I-7. Composition of biogas fibres® produced in by BENAS

	Biogas fibres® from Fibreplus ® system (GNS)
DM (%)	50-90
OM (% of DM)	86-90
NH4-N (kg/ton)	0,02-0,6
pH	5-7

I.7 Purified water extracted from digestate

Permeate water after reversed osmosis contains very low concentrations of nutrients (N, P, K), minerals, salts, and organic matter. The efficiency of the separation depends on the type of membranes used, the process operation conditions (pressure, type of membranes, temperature) and the pre-treatment cascade e.g. (multiple) solid separation step(s), ultrafiltration/nanofiltration/vibrating membranes, etc.
Sometimes a polishing step with an ion-exchanger or active carbon filter is necessary to discharge within governing surface water limits.

Dischargeable water can also be obtained by using a biological treatment (nitrification-denitrification) before or after evaporation as respectively a pre-treatment or a polishing step. This is the for example necessary when condensate ("ammonia water", Chapter **Fout! Verwijzingsbron niet gevonden.**) after evaporation of (liquid fraction of) digestate is discharged or re-used as process water.
Table I-8 shows some indicative values, based on analyses done on permeate after reversed osmosis on the liquid fraction of digestates.

Table I-8: Analyses on different types of purified water extracted from digestate

	Permeate Industrial pilot 1 [1]	**Permeate Industrial pilot 2** [1]	**Permeate VSEP filtration** [2]	**Permeate Ultrafiltration+ RO** [3]	**Permeate Ultrafiltration+ RO** [4]	**RO** [5]
pH	8.28 ± 0.12	9.31 ± 0.11			8.1	
EC (µS/cm)	6.45 ± 1.1	8.14 ± 0.9	0.88	0.034		
Density (kg/L)			1			
Dry matter (%)	0.107 ± 0.007	0.190 ± 0.001	-		0.1	
Organic matter (% of DM)	2.8 ± 2.9	1.58 ± 1.30				
COD (mg O2/L)	37.0 ± 0.8	27.1 ± 2.3	92 ± 42			
TKN (mg N/L)	641 ± 11	820 ± 0		88.5	85	
TN (mg N/kg)			94 ± 40			<160
Ammonium total (NH4+ and NH3) (mg N/L)	639 ± 28	787 ± 41		72.5	25	20
Nitrate (mg NO3/L)	n.d.	n.d.				
Phosphorus (mg P/L)	2.9 ± 0.1	0.15 ± 0.00	110 ± 0.00	0.85		<2.5
Phosphorus (mg P-PO43-/L)	2.29 ± 0.02	0.09 ± 0.01				
TIC (mg CaCO3/L)	-	610 ± 10				
K (mg K/L)	646.08 ± 15.04	849 ± 98	110 ± 20	40.9	45	

[1] Average of 2 samples of permeate after industrial scale membrane filtration pilot units e.g. nanofiltration, 2 phase RO (Ama Mundu Technologies SA) on the liquid fraction of digestate after screw press (Adam et al. 2018).

[2] Average of 4 samples permeate after 2 step VSEP reverse osmosis of the liquid fraction of digestate after rotating drum (Vaneeckhaute et al. 2012)

[3] Mean from 9 samples permeate after ultrafiltration + reverse osmosis of the liquid fraction of digested cattle manure after screw press and centrifuge (Ledda et al. 2013)

[4] 1 sample of permeate after ultrafiltration + reverse osmosis (EnviTec) of the liquid fraction of digestate after screw press and centrifuge (Relatore, Mo, and Francesco Da Borso 2012)

[5] Analysis on 1 permeate sample after RO of mix liquid fraction and digestate (AMPower)

II. ANNEX II Niche markets

This chapter gives an overview of current and future potential niche markets and the barriers still to overcome before recovered nutrients can be successfully made available on the market.

II.1 Gardening products

There are several types of home garden products, granular multi-purpose organic fertilisers often containing dried poultry or cattle manure.
Most garden fertilisers are commercially available as pellets or granules in boxes or bags of between 1-2 kg and they are odourless (Rigby and Smith 2011).
Mineral concentrates or blends of recovered nutrient products could reach the required nutrient ratios of certain garden fertilisers (Table II-1) if they could be concentrated and dried to eliminate odours.

Adding of nitrogen containing substances, like ammonium nitrate, could help to increase the nitrogen content of the organic fertiliser by creating tailor-made fertilisers (Vlaco vzw).
Because the current gardening fertilisers are pellets or granules, thermally dried digestate products (blends), could fulfil the same role as currently available granular multi-purpose fertilisers (WRAP, 2011).

In practice, it would be ideal to mix the compost (55% DM) with a solid nitrogen rich product, avoiding the water content of the compost to be altered.
Ammonium nitrate or ammonium sulphate solutions added during composting would largely volatize the ammonia again, which has to be cleaned out of the air, resulting in a zero operation. Crystallized ammonium sulphate could prove useful here but is not yet produced at AD plants.
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Table II-1. Average nutrient content of some gardening fertilisers (Rigby and Smith 2011).

		N	P	K
Multi-purpose garden fertilisers	Some of them are made from organic constituents	5,5	3,3 (1,5 soluble)	4,4
Slow-release and organic fertilisers	Slow release nutrient source for fruit and vegetables	5,5	3,1 (0,5 soluble)	7,5
Ericaceous plant foods	Organic-based and a slow release product	7,8	5,8 (3,5 soluble)	3,5
Root booster' fertilisers	From sterilised ground bone. slow release to encourage root development	3,8	7,8 (0,9 soluble)	0
Rose and shrub feeds	Some are organic	2,5	2,4	17,5
Liquid tomato feed		3,8	1,6 (1,6 soluble)	4,6

Mineral concentrates are to the uptake by the plants and the water quality. In a system with nutrient solutions and drainage reuse, there is a particular need for flexible fertilisers that quickly dissolve well and contain low amounts of bulking agents.
In the long run, it would certainly be possible to use mineral concentrates from animal manure if both producer and user are willing to adapt and compromise. Odour could however remain an issue.
The producer must refine the fertiliser to make it more suitable for greenhouse horticulture. Fertiliser producers also demand high purity.

II.2 Soil substrates

Most of the digestate derivatives are less suited for use in substrate cultivation, because it is crucial that the application of nutrients is aligned with the plant uptake and water quality. In a system with nutrient solutions and re-use of drainage water there is a need for flexible fertilisers that dissolve quickly and contain only a small number of organic matter particles (ARBOR Project 2015; Dodde 2012).
Also, it should comply with the quality requirements for water uptake, amount of air, pH, EC and nutrients. Certain certification labels (e.g. RHP) guarantee these quality requirements are met, which will also limit the risks for the crops.
ANNEX III.3 explains a successful technology cascade that produces a nutrient solution for substrate cultivation.

Peat is nowadays still the most abundant component of potting soil. The potting soil industry is however searching for sustainable alternatives. The alternative material must however meet stringent criteria of potting soil producers.
A potting soil ingredient should not contain bio-degradable organic matter. Seedlings are usually susceptible to salt, and consequently potting soil producers ask for products with a very low electric conductivity value, preferably below 1 µs cm-1. Furthermore, the product should be odourless and free from pathogens. There are limits for heavy metals including Cu and Zn in growing media. Other contaminants of concern include residues of pesticides and herbicides which may be present in manure as well as in co-products. The presence of any phytotoxic compounds must be tested in a germination or phytotoxicity tests. Potting soil ingredients ideally have a slightly acidic pH.

Soil improvers with low nutrient contents may however become more valuable in the future because farmers are more and more aware of the importance of organic matter for maintaining soil quality. Soil improvers may thus be a profitable option for those products that cannot meet criteria for potting soil.

II.3 Fertilisers for organic farming

Using recovered nutrient products as a resource for fertilisers that are accepted for bio- or organic farming seems straightforward because the choice of fertilisers for organic farming is quite limited. However, there are strict rules to comply with. For example, one cannot use chemicals such as polymers in the nutrient recovery process.
An ideal organic fertiliser has a high organic matter content, slowly available nutrients and high N/P ratio (Smit et al. 2000).
Some of the recovered nutrient products, like struvite or renewable calcined phosphate, could be suited for this. Struvite is a slow release P fertiliser and can be used to satisfy plant needs for phosphorus. Currently only struvite from wastewater treatment plants is approved. Renewable calcined phosphate can also be used to satisfy plant needs for phosphorus. The total phosphorus concentration of this product is about 20% P_2O_5. However, there are some concerns about the high energy consumption to produce the renewable calcined phosphate. The extraction and transport of soft rock phosphate requires comparable amounts of energy.

Biochar from plants and wood can also be a good alternative as soil improver. Biochar is seen as a method for carbon sequestration.
Furthermore, certified organic farms have to comply with strict rules, which can differ from association to association they work with.

II.4 Nutrient source in biological water treatment

Ammonia is used in several areas of water and wastewater treatment, such as pH control, in solution form to regenerate weak anion exchange resins, in conjunction with chlorine to produce potable water and as an oxygen scavenger in boiler water treatment.
Industrial waste water treatment with activated sludge (nitrification-denitrification) sometimes has to cope with lower COD removal efficiencies and floating sludge due to shortage in nutrients (N,P, micronutrients). This is seen in pulp-and paper industry wastewater ("white water"), forest industry wastewater treatment and in sectors where a lot of process water going to the wastewater treatment. Therefore, urea (40%) and phosphoric acid (75%) are dosed as macronutrients. The amount depends on the amount of COD in the influent.
Recovered nutrients (N and P) can be cheap alternatives for these industries.
Some companies can be afraid to try these "new" recovered nutrients, because their activated sludge system can be sensitive to contaminants, chemicals, detergents or peaks in COD. Tests at lab scale with their active sludge could be necessary to persuade them that the recovered nutrient products are not toxic for their active sludge and the required permits (e.g. resource declaration) should be requested.

Examples

A beverage industry only treating relatively small amounts of wastewater (e.g. 30m³/day) and COD requires only 0,36 L of Phosphoric acid (75%) and 6,6 L of urea (40%) per day. Replacing this with ammonia water (15%) would mean 22 L ammonia water/day. If mineral concentrate (6,12 g N/kg and 0,17 g P/kg) would be used, 190 L should be supplied. This would fill in 25% of the amount of P required as a macro nutrient.

A paper industry treating 200 m³/hour uses 80m³ of urea per week and 20m³ of phosphoric acid per month. Using ammonia water to complete the N demand would require 68m³ ammonia water (15%) per week or 590m³ of mineral concentrate.

A wastewater treatment from a chemical company treating 500 m³/hour uses 0,5m³ of urea and 2L of phosphoric acid per day. Using ammonia water to complete the N demand would require 1,7m³ ammonia water (15%) per day or 14m³ of mineral concentrate.

II.5 Chemical industry

II.5.1 Ammonium sulphate and nitrate

In 2018, ammonium sulphate was used mainly (95% of world consumption) as a nitrogen fertiliser material. Industrial use of ammonium sulphate accounts for only about 5% of world consumption.
Ammonium sulphate is produced as a crystal by three different processes: (1) synthetic manufacture from pure ammonia and concentrated sulfuric acid, as a by-product of gas cleaning in coke and coal gasification plants, (3) from ammonia scrubbing of tail gas at sulfuric acid (H_2SO_4) plants, and (4) as a by-product of the production of caprolactam ($(CH_2)_5COHN$), Methyl Methacrylate and acrylonitrile (GEA 2010).
Recently, the world-wide supply of ammonium sulphate has increased somewhat, in part due to the production of ammonium sulphate by direct reaction crystallization from (spent) sulfuric acid and ammonia. The additional production capacity of ammonium sulphate has not been sufficient to satisfy the market requirements, therefore there is still room for recovered ammonium sulphate (GEA 2010).
As one might expect, the price of ammonium sulphate varies with the purity and particle size of the crystals, i.e. small crystals (< 1mm) are worth 3 times less than larger "granular" ones (2-3 mm).

Other industrial applications include leather, textiles, flame retardants. In baking applications, it functions as a dough conditioner and dough strengthener in bread products. It supplies nitrogen to the yeast for nourishment aiding in yeast function while promoting browning. It is recognised as a food additive (E515) in the EU and therefore it should be food grade quality and the legal constraints (i.e. end-of-manure status) probably still hinder its use as food additive.

Ammonium nitrate(AN) is used as hardener in the production of fibreboards and MDF. In the production of fibreboards, a long processing time is needed for mixing the raw material (wood) and the glue. Also, the adhesive must dry quickly during pressing to achieve a high production speed. This is possible by adding a temperature-sensitive hardener to the adhesive. As hardeners, ammonium salts, such as ammonium nitrate, sulphate, etc. are usually added to the glue (except for PF glue).
The release of acids lowers the acidity (pH), which promotes the drying of the glue. The choice and amount of hardener depends on the process conditions. Without the addition of a hardener, the number and complexity of the process conditions increases. In order to slow down the drying before pressing, ammonia is added as buffer substance.
Some producers of wood boards have expressed interest in AN solution or crystals as secondary raw material. Sometimes ammonium sulphate is used because this is cheaper, but AN is preferred because it is more stable and performant.
Yet, they require the product to have no impurities and they cannot specify which elements exactly are considered as impurity. Therefore, they would like to do some tests with the product (minimum 40%N) first and they would currently they need 3000 ton AN solution/year and no minimum volume supply is required.
If the product meets the requirements, a competitive price has to be negotiated.
Ammonium nitrate solutions with more than 28% nitrogen by weight compared to ammonium nitrate must successfully pass the detonation test defined in (EC) Regulation n° 2003/2003 In order to be free in circulation in the internal market (Seveso-inspectiediensten 2009). They must also meet a certain number of technical requirements regarding their porosity, the size of the particles, the pH and the percentage of impurities (e.g. a very low limit for organic substances).
Ammonium nitrate could be a precursor for explosives when the water is removed by evaporation (Regulation (EU) No 98/2013 on the marketing and use of explosives precursors). Again, a very high purity is required which may be a limiting factor. Recovered ammonium products typically have a strong odour.

II.6 Ammonia as an energy carrier

II.6.1 NH_3 fuel cells

II.6.1.1 Solid Oxide Fuel Cells

Fuel cells provide an opportunity to develop thermodynamic systems that generate electricity on the basis of electrochemical reactions by consumption of reactants from external sources. Moreover, fuel cells are recommended because of their high efficiency, low environmental footprint and attractive technology for the direct conversion of fuel to electricity.
Among these different types of fuel cells, Solid Oxide Fuel Cells (SOFC) have a big advantage on combination of environment-friendly power generation with fuel flexibility. In recent years, ammonia (NH3) has emerged as a promising fuel for electricity generation in SOFCs (Afif et al. 2016).
Considering the electrolyte and electrodes, the direct ammonia-fed SOFC-H is the most promising energy source for next-generation fuel-cell technology. However, its development is not yet at the commercialization stage and further investigation is required.

II.6.1.2 Internal combustion engine

Ammonia has been proposed as a practical alternative to fossil fuel for internal combustion engines (Olson and Holbrook 2012). Ammonia was used during World War II to power buses in Belgium, and in engine applications prior to 1900.
Since ammonia contains no carbon, its combustion cannot produce carbon monoxide, hydrocarbons or soot and high compression ratios prevent NOx production (David et al. 2014).
However, ammonia is a much less active fuel compared to gasoline, it doesn't combust easily on its own. But, with a small amount of combustion enhancer (gasoline, diesel or pure hydrogen) mixed in, it burns and releases enough energy to drive the engine. A prototype of an NH3 car has already been built, equipped with a control system that makes the perfect mixture with combustion enhancer (gasoline, diesel or pure hydrogen), which burns and releases enough energy to drive the engine on NH3 with a radical reduction in carbon and greenhouse gas emissions (http://www.nh3car.com/how.htm).

However, alternative fuels first have to overcome a technology-change cost (CAPEX) hurdle, which, for the incumbent fuel, is always zero (Lloyd's Register 2017).
This underlines the importance of policy and regulation as drivers for change, since market forces alone appear unlikely to prove sufficient.(Brown 2017)
Still, some entities in the maritime sector operate in unique, niche markets where ammonia fuel technologies are already competitive, and they have an unrivalled opportunity – today – to deploy these technologies (Brown 2017).

II.6.2 Ammonia as a hydrogen carrier

There is a demand for ammonia as a hydrogen carrier (reductant) in emerging emission control (DeNOx) technologies in industrial and automotive applications.
Selective (non-)catalytic reduction for flue gas cleaning of NOx is used in a wide range of capacities in all kinds of combustion installations in sectors like waste incineration, energy plants, metal industry and greenhouse horticulture. The scrubbing process is also used to remove NOx from NOx rich gases produced in a relatively small amount at metal-dissolving, nitric acid and chemical plants, etc. (Anon n.d.).
Selective (Non-)Catalytic Reduction reduces NOx (the oxides of nitrogen) to N2 and H2O by adding NH3 or urea according to the following this reaction diagram:

$$4NO + 4NH_3 + O_2 \rightarrow 4N_2 + 6H_2O$$
$$2NO_2 + 4NH_3 + O_2 \rightarrow 3N_2 + 6H_2O$$

II.6.3 Selective non-catalytic reduction (SNCR)

In SNCR, a mixture of steam and the reducing agent is injected in the flue gas of an incineration process, to the furnace. If ammonia is used as reducing agent, the optimal temperature is 930 to 980°C. If urea ($(NH_2)CO$) is used, the temperature needs to be even higher (950-1050°C) because it needs to be thermally cracked to NH3, which can then react as the reducing agent.
NOx removal efficiencies in SNCR range from 40 to 70% (Anon n.d.) .

Example

An incineration plant that processes 25 tonnes of waste an hour, emits 25 to 40 kg NOx/h. To reduce the NOx below the limit of 120 mg NOx/Nm³ this would require 100 L of ammonia solution (25% chemical grade). At a cost of 150€/ tonne of ammonia solution this would mean a yearly cost of 14.000€. A larger incineration plant claimed to use 1000 tons ammonia solution (25% chemical grade) per year, costing them 150.000€/year. Recovered ammonia water (10-20%) is perfectly suited to replace urea.

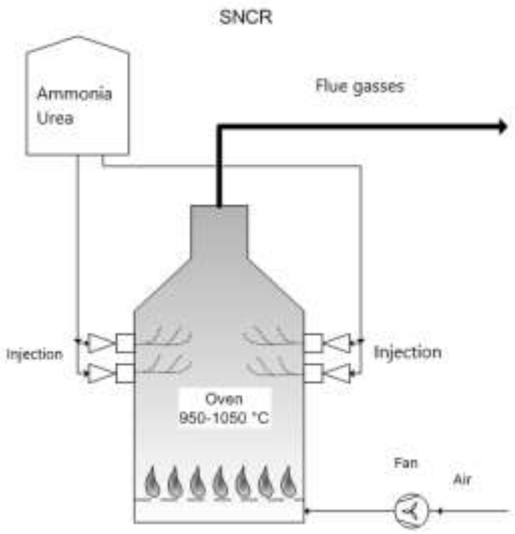


Figure II-1. Scheme SNCR (Emis: energie- en milieu-informatiesysteem voor het Vlaamse Gewest n.d.)

There are already waste incineration companies using only recovered ammonia water in their DeNOx process and have not had any problems with it. Lower concentrated ammonia water (10%) can also be used, because different concentrations of recovered ammonia water can be blended in one storage tank before usage.
Impurities in the recovered ammonia water are no issue for SNCR since there is no catalyst present which could be fouled.
In general, incineration plants would be able to be persuaded to use (lower quality) ammonia water for their flue gas cleaning (SNCR), if they can obtain it for a low price.
If only transport costs are taken into account, both parties (the biogas plant and the incineration plant) are reducing their costs.

II.6.4 Selective catalytic reduction (SCR)

SCR is using a catalyst to accelerate the deNOx process and improve the efficiency. The optimum process temperature lies between 320 – 500 °C depending on the catalyst (oxides of vanadium, wolfram, molybdenum or other metals).

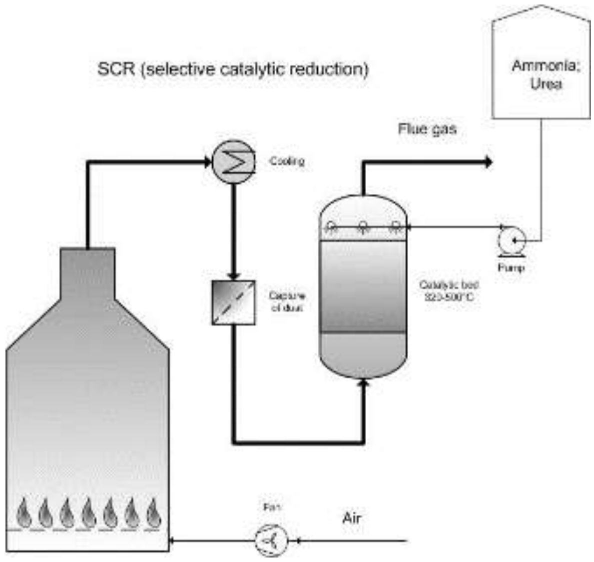


Figure II-2. Scheme SCR (Emis: energie- en milieu-informatiesysteem voor het Vlaamse Gewest n.d.)

NOx removal efficiencies with SCR range from 80-95% (Anon n.d.) with incoming concentrations of NOx of some g/Nm³ up to 1 000 000 Nm3/h. This is a higher NOx reduction yield compared to SNCR. Smaller installations (<5MWth) have a lower yield (80-85%).

The SCR installation can be placed immediately after the boiler ("high-dust" switching) or after the dust filters or scrubbers ("low-dust" switching). This requires the flue gas to be heated to reaction level. The ammonia source is injected into the exhaust gases prior to their passing into the SCR (Chironna and Altshuler 2001).

The use of recovered ammonia water as a reducing agent would also be possible in SCR but requires a higher purity because of the presence of the catalyst. The following components must not be present in that the recovered ammonia water:

- SO_3 and Cl, since they react with ammonium and water to form ammonium sulphate, ammonium bisulphate and ammonium chloride. These condensed ammonium salts can cause reversible deactivation of the catalyst, by lowering the active surface of the catalyst and hereby reducing its separation efficiency. They are emitted as aerosols that are difficult to separate.
- Dust, because it contains potassium and sodium, which can precipitate on the catalyst causing poisoning or irreversible deactivation of the catalyst.

Some ammonia solutions recovered from bio-waste can already meet these quality specifications (personal communication, 2018). Yet, plants using SCR are reluctant on using recovered ammonia water because, the flue gas cleaning process is far from their core business, and the reduced costs related to the recovered ammonia solution are relatively small compared to the risk they would take by poisoning their catalysts.

The use of recovered ammonia water could also help contribute to the green image of the plant and reduce the costs of buying chemical grade ammonia. If the whole chain (biogas plant, provinces, incineration plants of municipal waste) could be involved, this could facilitate the logistic and supply aspect and raise more public awareness about recycling.

II.6.5 SCR as deNOx for exhaust gasses from combustion engines

In the European Union emissions of nitrogen oxides (NOx), must be limited by EU exhaust emissions standards and Real Driving Emissions legislation. One in two new cars registered in Western Europe is a diesel vehicle, which means the number of cars with SCR technology is set to rise.
The SCR reaction is the same as described above, the reducing agent is called "Diesel exhaust fluid (DEF)" better known under the commercial name "AdBlue®" or AUS32 under the ISO 22241. DEF is an aqueous urea solution made with 32.5% urea and 67.5% deionized water.

ISO 22241 lists strict requirements for maintaining concentration and purity of ingredients critical to the proper functioning and longevity of the SCR system. It also contains a description on the methods to be used for determining these parameters and reproducibility of the results.

An important phrase in the ISO 22241 states that AUS 32 is an aqueous urea solution, manufactured from technically pure urea – with no addition of any other substances – and pure water. Technically pure urea is industrially produced grade of urea with traces of biuret, ammonia and water only. The specifications of AUS 32 are listed in Table II-2.

Table II-2. Specifications for AUS32 in ISO22241

Characteristics	Unit	Min	Max
Urea content	% (m/m)	31.8	33.2
Density at 20°C	Kg/m³	1087.0	1093.0
Refractive index at 20°C		1.3814	1.3843
Alkalinity as NH3	%(m/m)		0.2
Biuret	%(m/m)		0.3
Aldehydes	Mg/kg		5
Insoluble matter	Mg/kg		20
Phosphate (PO4)	Mg/kg		0.5
Calcium	Mg/kg		0.5
Iron	Mg/kg		0.5
Copper	Mg/kg		0.2
Zinc	Mg/kg		0.2
Chromium	Mg/kg		0.2
Nickel	Mg/kg		0.2
Aluminium	Mg/kg		0.5
Magnesium	Mg/kg		0.5
Sodium	Mg/kg		0.5
Potassium	Mg/kg		0.5

The strict requirements of the composition and purity of AUS 32 described in the ISO 22241 make it practically impossible for recovered ammonia water to be used as such as AUS 32. Even if a purity similar to AUS 32 could be reached by upgrading, ammonia water would still not contain urea (but ammonium).

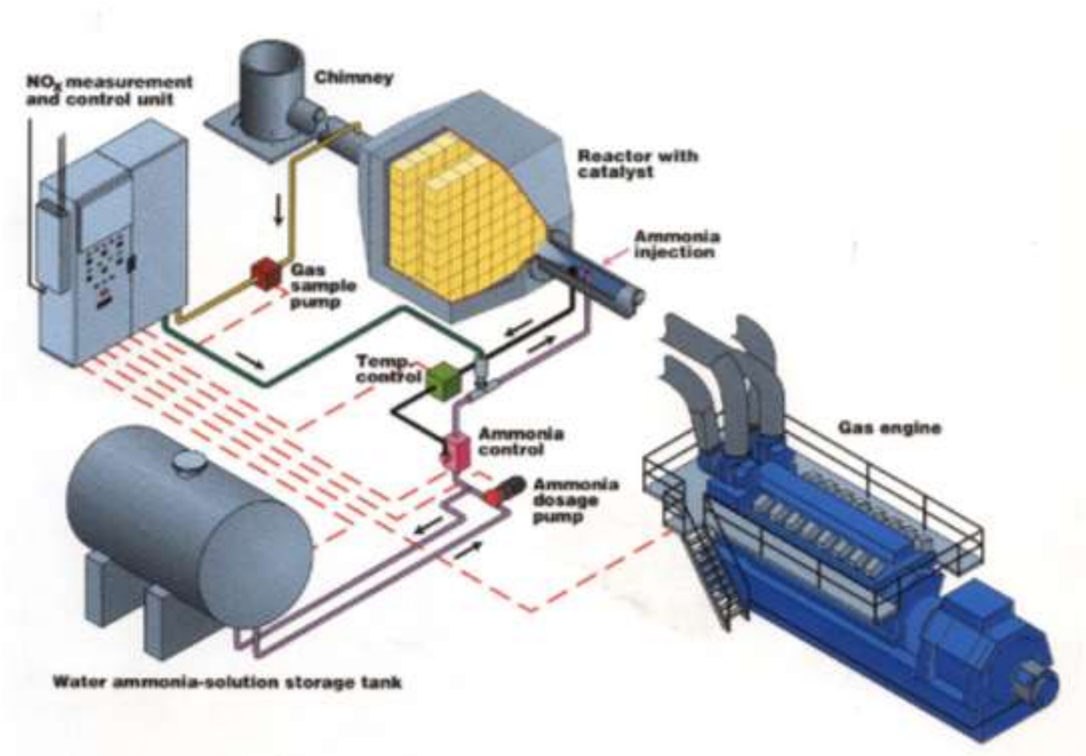
It would also not be possible to sell it under the name “AdBlue®” and suppliers of SCR systems would not want to use this product in their systems, since it does not meet the ISO22241 specifications and therefore they cannot give guaranties on its performance.
However, the European Emission Standards do not mandate the use of specific technologies (and products) to meet the standards.
So, there is a prospect for recovered ammonia water being used as DEF, but only if it is proven to work with a certain SCR technology and could pass all safety requirements for quality, handling, testing, transportation storage, and refilling.

Furthermore, it would be very difficult to be competitive in the AUS 32 market, since AdBlue® is produced in large quantities and sold with a profit margin of only a few €cents per litre (personal communication, 2018). This makes it even for the large manufacturers difficult to produce a competitive product and they can sometimes only achieve this by having the do this by having their producing facilities on the most opportune locations. The easiest way to use recovered ammonia as AUS 32 would be by supplying it to a producer of AUS 32 as secondary raw material.

Gas engines on natural gas or other fuels (e.g. biogas) are used more frequently as emergency power supply. The NOx emission limit for gas engines on natural gas and biogas is 190mg NOx/Nm^3 (https://www.amps.org.uk/eu-emissions-update). NOx excess can again be removed with an SCR gas cleaning system using a urea solution as reductant.

To be an eligible alternative reductant for SCR, the purity of the products needs to be proven before it can be used. Also, a file needs to be made to get a resource declaration from the ruling authorities for this specific product application. The file should scientifically substantiate that the product is suited for this application. It should also describe the composition and purity required to guaranty the safety for the SCR process.

Figure II-3.SCR in gas engine. Source: Wärtsila Nederland



III. ANNEX III Success stories

III.1 YARA synergies

In Norway, mineral fertiliser producer Yara cooperates with the VEAS wastewater treatment plant in Oslo, which produces ammonium nitrate by stripping the ammonium from the wastewater.

The plant was originally designed for sulphuric acid but in 1998 it switched to 55% nitric acid because farmers said they did not want ammonium sulphate because of its acidifying effect on soil. Furthermore, Norsk-Hydro (now Yara) was prepared to supply nitric acid and purchase the ammonium nitrate, which relieved VEAS of finding customers for its recovered N. This synergy is convenient for both parties.

However, ammonium nitrate is a powerful oxidising agent and in the presence of organic matter is liable to explode. Consequently, Yara has set a quality limit of 100 ppm total organic carbon. On occasions the TOC-limit has been difficult to achieve, but mostly the product is acceptable to Yara. The economics of the process lie in this control program and in optimising the air flow. At least 90% of the ammonia is air-stripped and recovered from the filtrate. VEAS produces about 3000 tonnes ammonium nitrate (dry weight) per year.
Yara uses the ammonium nitrate for the manufacturing of calcium nitrate or sells it to the wood industry (Yara International ASA 2017).
The plant manager estimates the cost for replicating the plant (wastewater treatment for 650,000 people equivalents) on 586,000€.
Other Yara plants that could use ammonium nitrate are:

- Sluiskil in the Netherlands. This plant produces N fertilisers and industrial chemicals.
- Tertre near Mons in Belgium. This plant produces nitrogen fertilisers for markets in France, Germany, Belgium and the Netherlands as well as industrial chemicals - ammonia, aqueous ammonia, ammonium nitrate and nitric acid - for European industrial customers.
- Vlaringen near Rotterdam. This plant produces niche products like potting soil fertilisers. In this rare case, there can also be a market potential for bulk liquid ammonium nitrate. Since, the Yara plant is located on less than 50km from Westland greenhouse, which uses high quality liquid fertilisers, transport cost are relatively low, making this an interesting sales opportunity.

III.2 Magic dirt®

In the US there is a growing trend of digestate products making strides at penetrating the horticulture and agriculture markets. Originating form anaerobically digested organic farm waste, Magic Dirt® is sold as a soil amendment product on the shelves of 2,500 WalMart stores in America (www.magic-dirt.com).

III.3 Van der Knaap

In the past seven years, the Dutch company Van der Knaap and partners Opure, Triqua International and Forteco Services, have been developing a fertiliser solution derived from digestate. The technology cascade looks as follows:

- Calcium and Magnesium -phosphorus salts are precipitated from the digestate after addition of Mg and Ca.
- Biological nitrification converts ammonium to nitrate
- Potassium carbonate is added, forming potassium nitrate, which is concentrated together with humic acids by means of membrane filtration.
- Blending of these different nutrients products creates an NPK fertiliser solution

(Van der Knaap 2019; Van der Knaap et al. 2018)

Currently a stable system is running in a continuous set-up and the nutrient solution is applied on practical level in organic hydroculture outside Europe. This because European legislation doesn't allow it for organic hydroculture. More research is being done to produce also fertilisers from manure for professional greenhouse horticulture (personal communication, 2019).

III.4 Crystal Green®

The production of Crystal Green® by the company Ostara, is a good example of a fully developed value chain for a recovered phosphorus from wastewater.
Ostara's fluidized bed reactor (the Pearl® reactor) produces struvite pellets from digested wastewater treatment sludge. The pellets are dried and classified on site in different specific pellet sizes.

Ostara provides the technology and design of the reactor and takes care of the process technological quality control to be able to guarantee the constant quality of the struvite salts. They collect the different pellet sizes, packages and markets them as Crystal Green® (N-P-K: 5-28-0 + 10% Mg), a high purity, slow-release mineral fertiliser (Ceulemans and Schiettecatte 2013; Notenboom et al. 2017). Normally, struvite is not soluble in water, but by stimulating the citrate production of the germinating plant roots Crystal Green® releases more phosphate per application (Colenbrander 2018).
The operational costs for the Pearl® process are completely covered by the sales of Crystal Green®.

Crystal Green® is certified in the UK as EG fertiliser and can be used in the Netherlands within a derogation (Colenbrander 2018). It is also REACH certified and meets with the standards of the European fertiliser regulation.

The wastewater treatment plant in Amersfoort (NL) has a Pearl reactor® since 2016 and the pellets are marketed via Agro-Vital Groningen for 2,5€/kg (Ceulemans and Schiettecatte 2013; Leenaerts 2011).

III.5 Recovered phosphate products allowed as P fertiliser under derogation in the Netherlands

A few years ago, official negotiations put an end to the use of mineral phosphate fertilisers on derogation farms in the Netherlands, with the result that the useful P starter fertilisation (e.g. for corn), was not allowed anymore.
After some lobby work, 2 alternatives for mineral P fertiliser are allowed (i.e. derogation) to be applied for row fertilisation of silage maize, on plots with a low phosphate status.

Figure III-1. Green Phosphate pellets.

Groen Fosfaat® (English: Green Phosphate) is an organic phosphate fertiliser with a favourable nutrient ratio produced from animal manure. For nitrogen, the fertiliser does count as animal manure in manure accounting balance, since it contains nitrogen from animal manure, which is also limited to 170 kg/ha/year. Green phosphate is sold for 300€/ton, the price fluctuating according to the place of delivery. For now, the market for Green Phosphate is still marginal (DLV Advies, MeMon, and EcoEnergy 2019).

Figure III-2. Physiostart P Plus micro-granulates.

Micro-granulates for precision fertilisation, containing mineral P, were also not allowed to be used on Dutch derogation enterprises. Producer Timac Agro went looking for an alternative to the mineral P for its start fertiliser Physiostart. After some research and testing, they created Physiostart P Plus, with recovered P (Mg-struvite), which is -like Green Phosphate- allowed to be used on derogation farms (Verkerk 2016).

III.6 P-poor soil improver

Fibrous organic products recovered from manure or digestate may serve as an alternative for peat in potting soil for the consumer market.
A potentially suitable material is currently produced by Groot Zevert Digestion in Beltrum, The Netherlands, where the solid fraction of co-digested manure is separated into organic fibrous fraction and a P fertiliser by using acid and base.
A fibrous material from manure or digestate that meets all these criteria can be sold to the potting soil industry for a price of about € 10-15 m^3 which is generally higher than the market value of soil amendments. This may compensate the costs made to meet the criteria of the potting soil industry.

III.7 Synergy between Groot Zevert Vergisting & Group Op de Beeck

In Chapter 3.1.4, the Pilot in the Netherlands "Mineral Fertiliser Free Achterhoek" was described. To comply with the conditions for the pilot status posed by the ministry, the "Green Meadows Fertiliser" (GMF) had to consist out of a certain percentage of recovered nitrogen. During start-up phase in spring 2019, the nitrogen concentration of the GMF was not obtained and GZV went looking for recovered ammonia to boost the N content of their fertiliser solution. SYSTEMIC Associated Plant Group Op de Beeck (Belgium) produces ammonia water from digestate of bio-waste. ADR[6] transport was arranged to GZV in Beltrum (NL). Ammonia water could be transported across the Dutch border as a product with only a CMR[7] transport- document because it also has been certified by Vlaco[8] to be used as soil improver/fertiliser (personal communication, 2019).
At the GZV plant, two loads of 150m^3 of 20% ammonia water were unloaded via a direct stainless-steel piping to a mixing tank, where it was mixed with GMF (4% of the total volume) to boost the nitrogen concentration up to 1,5%.

III.8 ICL Fertilisers Amsterdam using struvite from Waternet

Waternet's Amsterdam West wastewater treatment plant treats the wastewater of more than 1 million inhabitants in the Netherlands. Since 2006, 600.000 tons of sewage sludge per year are digested on site creating green energy. The digestate is dewatered by a centrifuge,
Yet, a few years ago a massive build-up of struvite crystals (N-P-K, 5-28-0) in the sludge holding tank, centrifuge and the pipelines was discovered, causing wear and tear on the centrifuge. Two important factors where causing this struvite deposition.

Figure III-3. Struvite depositions in the pipes of the sludge holding tank.

1. The phosphorus captured in the biomass of the bacteria was released during anaerobic digestion and reacted with the present ammonium to form Mg-struvite.
2. The design of the digester, stripping CO_2 through turbulence favoured the formation of struvite crystals by a pH rise, pushing the equilibrium towards struvite formation.

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[6] **A**ccord européen relatif au transport international des marchandises **D**angereuses par **R**oute
[7] **C**onvention relative au contrat de transport international de **m**archandises par **r**oute
[8] Vlaamse Compost Organisatie; EN: Femisch Compost Organisation

After a long procedure of testing, Waternet build the AirPrex® system, that precipitates 95% of the ortho-phosphate as struvite in a controlled way in a reactor after adding 32% $MgCl_2$.
Today, Waternet Amsterdam produces 500-900 ton struvite per year. This is sold to ICL Fertilisers Europe (50-100€/ton), also located in Amsterdam, using it as resource for the production of tailor made fertilisers (Veltman 2012).

Figure III-4. Recovered Struvite.

Waternet is owned by the municipality of Amsterdam which has high ambitions in terms of circularity and P-recovery. Currently, only 20% of the total phosphorus present in the digestate can be recovered as struvite and they aim to increase the percentage of P recovered from their sludge. Moreover, they intend to dry sludge with residual heat of the digester and to use it as a fuel for e.g. cement industry. For this latter purpose, a low P content is desired as it increases the economic value of the sludge as a fuel.

III.9 NDM

NDM is a large biogas plant, located in Velen, District Borken in Germany. The region has to cope with nutrient surpluses (mainly from liquid manure) through intensive livestock farming. In July 2014, NDM's current managing director, Doris Nienhaus, developed a concept idea for a biogas-nutrient recycling plant running on regional manure (District of Borken).
Together with ENVIMAC Engineering GmbH and e4 Architekten the project grew in 12 months to a model for modern agriculture.

The aim of the biogas-nutrient recycling plant was to make an important contribution to reducing the manure surplus in the district of Borken by the practical development of environmental technologies for the treatment of manure. In particular, to make marketable concentrated end products which contain recovered valuable substances (N, P, K, organic matter) in a way that no (new) waste streams are created.
The end products produced by the system are solid fraction of manure, ammonium sulphate solution and phosphorus rich ashes (from incinerated solid fraction) which can be blended together in preferred ratios.
The plant is operational since 2019. The digesters are fed with 100% manure, i.e. approximately 100.000 t pig manure per year and 100.000 t cattle manure/year. The manure is supplied by 90 founding members, all farmers from the Borken district.
These farmers have laid the foundations of their joint venture which includes the responsibility for risks, entrepreneurial commitment and, last but not least, equity capital of around 2.4 million euros). The project is considered unique in Europe (https://www.ndm.company/, personal communication, 2018).

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Horizon 2020

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