FertiCovery

Technology upscaling report

Deliverable 5.2

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Abbreviations

AD	Anaerobic digestion
AN	Ammonium nitrate
AS	Ammonium sulphate
BAT	Best Available Technique
BBF	Bio-based fertiliser
BTG	Biomass Technology Group
CMC	Component Material Category
CRCF	Carbon Removal Certification Framework
D	Deliverable
DM	Dry matter
EBA	European Biogas Association
EBC	European Biochar Certificate
ECN	European Compost Network
EU	European Union (EU27 from 2020)
FM	Fresh matter
FPR	Fertilising Products Regulation
GHG	Greenhouse gas
ha	Hectare
kt	Thousand tonnes
LF	Liquid fraction
MS	Member State
MSW	Municipal Solid Waste
Mt	Million tonnes
N/A	Not available
NEO	Nitrogen-enriched organic fertiliser
NR	Nutrient recovery
RENURE	Recovered Nitrogen from Manure
RO	Reverse osmosis
t	Tonne
T	Task
TBD	To be determined
TRL	Technology Readiness Level
VFA	Volatile fatty acids
WP	Work package
wt	Weight
WWTP	Wastewater treatment plant
yr	Year

Summary

This report assesses the scale-up potential of bio-based fertiliser production from secondary raw materials across multiple pathways, ranging from mature technologies such as composting and anaerobic digestion to emerging approaches. For each pathway, the feedstock-based production potential, market-based demand potential and current production level are estimated, and the gap between the current and potential production is expressed as a scale-up potential and a scale-up factor. Table 1 provides an overview of the results. The pathways differ significantly in scale, maturity and the binding constraint for scale-up: for some products feedstock availability is the binding factor, whilst for most products the market demand determines the scale-up potential.

Table 1: Overview of estimated current production and scale-up potentials for all pathways in Mt product (FM) per year in the EU27.

Product	Current production	Feedstock-based potential	Market-based potential	Potential to scale-up[b)]	Scale-up factor[c)]
Compost	17.6	39.9	31.2	13.6	0.8
Whole digestate	450	1,063	N: 2,007 P: 1,156 K: 5,708	613	1.2
Digestate solid fraction	50	101	N: 402 P: 139 K: 6,861	51	1.0
Mineral concentrate	0.8	24.5	22.0	21.2	26
Solid potassium fertiliser	0.015	3.7	3.4	3.3	223
Struvite	0.01	0.2	0.4	0.3	27
Ammonium sulphate	0.1	17.7	4.7	4.6	46
Ammonium nitrate	0.02	30.8	8.6	8.5	427
Biochar	0.03	1.7	0.2	0.2	6
Organo-mineral fertiliser with biostimulant properties[a)]	0.00005	0.3	0.006	0.006	32-11,359
Liquid organo-mineral concentrate	0.3	38	2	1.7	6
Granular organo-mineral fertiliser	0.0000024	22	0.2	0.2	64,230
Nitrogen-enriched manure slurry	0.03	844	0.08	0.05	1.7

[a)] Average of case studies #12 and #14. [b)] calculated as minimum of feedstock-based and market-based potential, minus current production. [c)] Calculated as potential to scale up divided by current production.

Figure 1 summarises the current production and potential to scale up for each pathway, expressed in Mt product per year, including moisture, if this is part of the product. Given the huge quantity of whole digestate, Figure 2 visualises the current production and potential to scale up of each pathway excluding digestate products.

It is important to note is that several pathways assessed in this report draw from overlapping feedstocks. These pathways should therefore be interpreted as alternative routes rather than additive ones. Scaling up one pathway may reduce the feedstock availability for others, and the choice between pathways will in practice depend on local conditions, infrastructure, regulatory status and economic viability.

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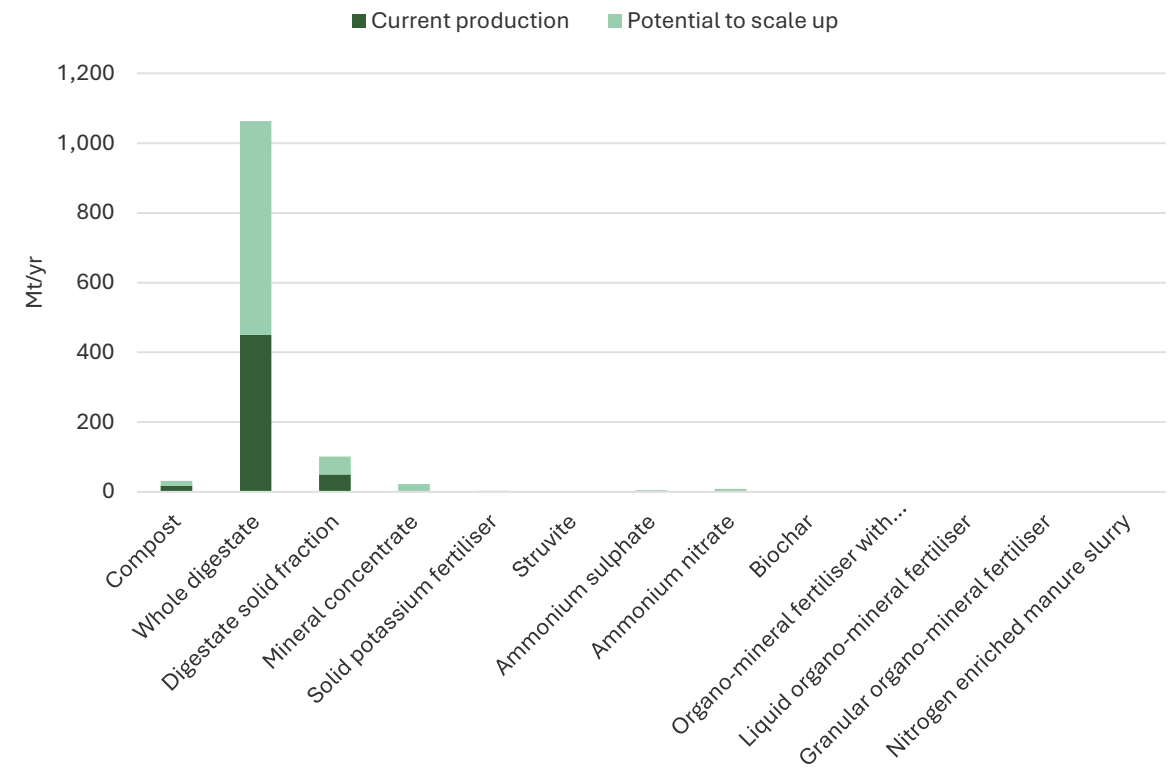


Figure 1: Current production and potential to scale up of each pathway.

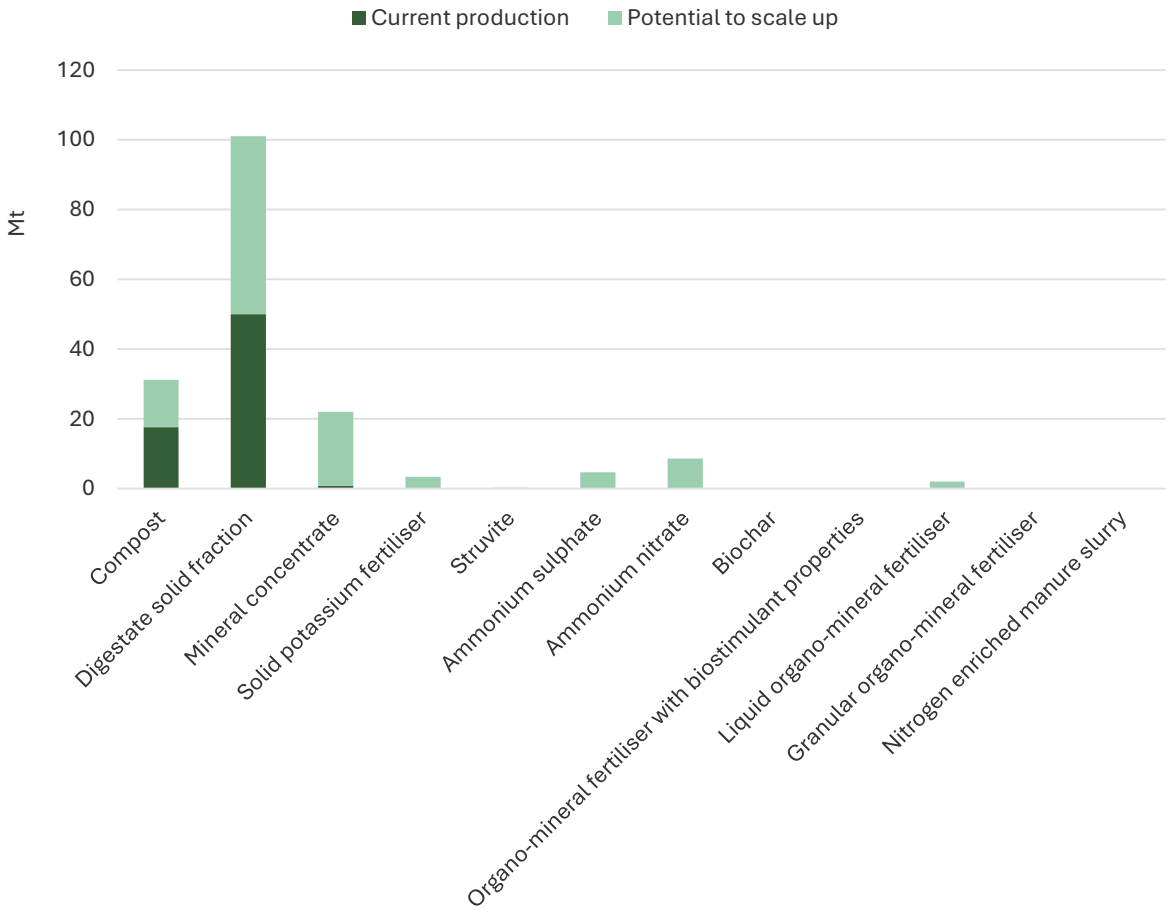


Figure 2: Current production and potential to scale up of each pathway (except digestate products).

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The current production, scale-up potential and main barriers of each pathway are briefly discussed below.

Composting is a fully mature technology, widely deployed driven by green waste and municipal bio-waste.

- *Current status*: approximately 17.6 Mt of compost is produced from 36 Mt bio-waste annually in the EU.
- *Scale-up potential:* an additional 13.6 Mt of compost can be produced representing 80% growth opportunity.
- *Main barriers:* scale-up is dependent on improved municipal waste collection infrastructure and the strict enforcement of the EU Waste Framework Directive regarding separate municipal bio-waste collection.

Anaerobic digestion is a fully mature technology widely deployed, with substantial scale-up potential constrained by the amount of livestock manure actively directed to AD plants.

- *Current status:* the EU produces roughly 450 Mt (FM) of whole digestate annually, and 50 Mt of digestate solid fraction.
- *Scale-up potential*: whole digestate has scale-up potential of 613 Mt (FM) for whole digestate and 50 Mt for digestate solid fraction, with scale-up factors of 1.4 and 1.0, reflecting the already substantial deployment.
- *Main barriers*: significant volumes of manure are applied to land without being currently processed via AD, transporting whole digestate over long distance (>10 km) is economically unattractive but there is still low adoption of solid-liquid separation due to regulatory constraints.

Mineral concentrate production from digestate via membranes-reverse osmosis is a commercially available technology, which treats the liquid fraction of digestate derived from pig manure. The formal recognition of RO-based mineral concentrates as a RENURE fertilising product under the Directive (EU) 2026/288 is the key regulatory driver, allowing application above the 170 kg N/ha manure limit, once transposed into national legislation.

- *Current status:* EU production estimated at 0.8 Mt per year, deployed primarily in the Netherlands.
- *Scale-up potential*: the potential is 21.2 Mt with a scale-up factor of 26.
- *Main barriers*: technology requires RO to qualify as RENURE fertilising product under the new framework[1], technologies utilising evaporation or ultrafiltration face strict manure application limits, the volume of concentrates to be transported over a long distance, restricts operational and economic viability to local, intensive livestock regions.

Potassium fertiliser from digestate evaporating mineral concentrate into solid potassium fertiliser acts as seasonal solution for winter months when liquid concentrate cannot be applied to land.

- *Current status:* documented commercial production is limited to 15 kt.

[1] The formal recognition as a RENURE fertilising product under the Directive (EU) 2026/288 is the key regulatory driver, allowing application above the 170 kg N/ha manure limit, once transposed into national legislation

- *Scale-up potential:* theoretical potential reaches 3.3 Mt targeting potassium-demanding crops, such as potatoes. The high scale-up factor, 223, primarily reflects the very low current production.
- *Main barriers:* high chloride content limits use to chloride-tolerant crops and the product remains classified as manure-based which complicates marketing, farmer acceptance and blending with other fertilisers.

Struvite precipitation: recovering phosphorus via this technology is mature and mainly applied as a practical post-digestion solution in WWTP.

- *Current status:* approximately 10.9 kt of struvite is produced annually with at least 37 operational plants in Europe, primarily at municipal WWTPs and potato processing facilities.
- *Scale-up potential*: production could increase by a factor of 27 to reach 310 kt though the market potential is higher if used in NPK blends.
- *Main barriers:* despite being approved for organic farming, organic farmers and the agricultural sector express reluctance due to concerns of contamination from sewage-derived products; therefore, wider uptake would benefit from quality certification schemes addressing uncertainty around the use of wastewater-derived products and potato processing facilities.

Stripping and scrubbing of ammonia extracting nitrogen from liquid fraction of manure based digestate via stripping and scrubbing into ammonium salts (e.g. **ammonium sulphate** and **ammonium nitrate)** is technically mature and has substantial growth potential due to its explicitly recognised RENURE status[1].

- *Current status:* EU production is low estimated at 0.1 Mt for ammonium sulphate and 0.02 Mt ammonium nitrate
- *Scale-up potential*: the technology exhibits a very large scale-up factor (46 for ammonium sulphate and 427 for ammonium nitrate) with a combined growth potential of over 13 Mt, i.e. 4.6 Mt ammonium sulphate and 8.5 Mt ammonium nitrate.
- *Main barriers:* possible delay of RENURE Directive implementation in national law; the bio-based salts are diluted compared to synthetic counterparts requiring much higher application volumes and increasing transport costs.

Slow pyrolysis to biochar: while pyrolysis of woody biomass is a commercially mature technology (with over 200 European facilities operational by end of 2024), the use of biochar as direct soil improver component or in growing media is limited in the EU27, due to agronomic and economic realities.

- *Current status*: total European biochar production is around 75 kt, of which very little directly applied to agricultural soils (approximately 26.5 kt).
- *Scale-up potential:* the estimated agricultural market potential is low (0.2 Mt) and relies largely on use as compost additive or element in peat replacement.

- *Main barriers:* biochar does not replace N, P or K and shows limited yield benefit in temperate European soils unless applied at unfeasibly high rates. Production costs are high, thus financial viability heavily depending on parallel income from carbon offset credits[2].

Hydrolysis: converting organic residues, sewage sludge, poultry feathers and food waste digestate, into **liquid and granular organo-mineral concentrates/fertilisers** via hydrolysis is an early-stage pathway constrained entirely by market demand and regulatory hurdles.

- Current status: EU production is negligible across most applications though one commercial sludge treatment technology operates at scale.
- *Scale-up potential:* theoretical potential ranges widely depending on the target crop and product (bio stimulants vs. fertiliser) but market adoption remains the main bottleneck.
- *Main barriers:* low nutrient concentrations, regulatory classification and early commercial stage. Products derived from sewage sludge face potential contamination issues and lack CE marking under the EU FPR. Specialized formulation (e.g. granular) often requires large volumes of additives (e.g. haemoglobin and peat).

Plasma process (nitrogen-enriched manure slurry) using plasma technology to enrich manure with nitrogen at the farm level has stalled at demo level and not yet successfully commercialised.

- *Current status:* the sole known technology supplier filed for bankruptcy in 2025.
- *Scale-up potential*: highly limited (0.05 Mt) despite significant theoretical feedstock availability
- *Main barriers:* the process requires very high electricity inputs (50kW per unit). The resulting product has no distinct regulatory advantage over raw, untreated manure under the Nitrates Directive. Further market development by a new technology provider would be needed before scale-up can realistically be assessed.

Assessment of scale-up factors

The scale-up factors in Table 1 reflect both the maturity of the technology and the gap between current and potential production and can be used to group the assessed pathways into three broad categories.

The products compost, whole digestate and the digestate solid fraction all have scale-up factors between 0.8 and 1.6. These low factors indicate that the technologies are fully matured and already widely deployed throughout the EU, such that the current production already represents a substantial share of the potential. These pathways consequently also have the highest absolute scale-up potentials of all assessed pathways, reflecting their large feedstock bases rather than untapped deployment potential.

The second category, encompassing mineral concentrate, struvite and ammonium sulphate shows scale-up factors in the range of 20-50, indicating commercially available technologies with meaningful current production but significant remaining scale-up potential. For mineral concentrate and ammonium sulphate particularly, the recent adoption of the RENURE framework represents a market driver that is expected to accelerate deployment in the coming years.

The third category encompasses technologies with a very high scale-up factors like solid potassium fertiliser, ammonium nitrate, and the organo-mineral concentrates/fertilisers. These technologies have low current production volumes (below 100 kt/yr), and the high scale-up factor primarily reflects early-

[2] EU Carbon Removal Certification Framework.

stage development rather than a proportionally large absolute opportunity. The nitrogen-enriched manure slurry stands apart from the other pathways due to the bankruptcy of the only known technology supplier and the absence of any regulatory advantage over untreated manure, resulting in a low scale-up factor and a very limited absolute scale-up potential.

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1 Introduction

1.1 Background

FertiCovery is supporting farmers, bio-based fertiliser producers and policymakers to remove barriers and promote nutrient recovery and the application of bio-based fertilisers, from secondary raw materials such as biowaste, manure, and wastewater. Within the FertiCovery project 25 value chains have been selected, as case studies and good practise examples. Figure 3 gives a brief overview of these value chains. Descriptions of each value chain can be found on the website of FertiCovery.

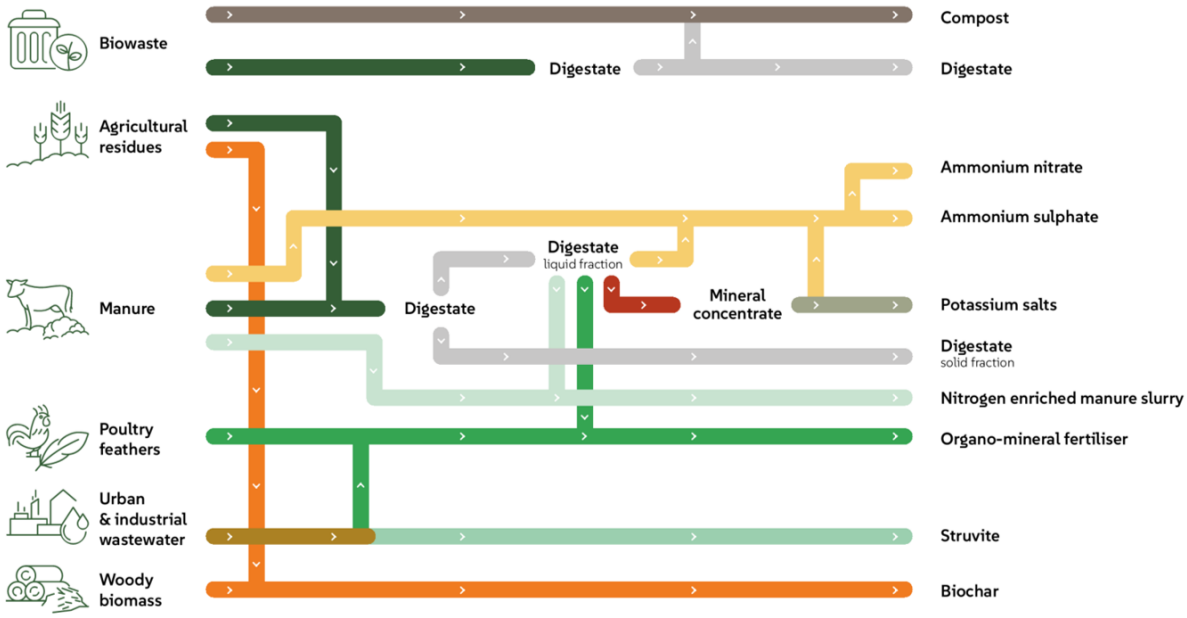


Figure 3: Visual representation of the 25 selected value chains.

1.2 Objectives

Considering feedstock availability, technology readiness and applicability of the bio-based fertiliser products, this report aims to provide insight into the potential to upscale the production and application of the 25 selected bio-based fertilisers.

1.3 Scope

The report sketches the potential role of the selected bio-based fertilisers in the EU market, in case remaining legislative, financial and market barriers and social risks would have been solved. These barriers and risks will be studied, and potential solutions will be provided in subsequent tasks. The final market uptake potential considering these barriers and risks will be presented in Deliverable D5.7 (forthcoming, December 2027). Thus, the current report can be seen as an initial assessment of the role of the selected value chains in the EU market for bio-based fertilisers. The report focusses on the 25 selected technologies that can be aggregated in the following main pathways, i.e. composting, anaerobic digestion, digestate treatment (to liquid nutrient concentrates by membranes and evaporation, and to potassium fertilisers), struvite precipitation, stripping and scrubbing towards ammonium sulphate and nitrate, slow pyrolysis to biochar and different hydrolysis treatments of different feedstocks.

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1.4 Approach

The estimation of the scale-up potential of each pathway is assessed in five steps:

- Step 1: description of the technology and product referring to the FertiCovery case studies
- Step 2: data collection on current production level of the bio-based fertilising product
- Step 3: assessment of the maturity of the technology, by data collection on size and number of installations, production capacities.
- Step 4: Estimation of the scale-up potential by estimation of the minimum of
    - Feedstock-based production potential, based on feedstock availability
    - Market-based production potential, based on size of plausible applications of the fertilising product
- Step 5: description of barriers to scale up.

First, the technology is briefly described, referring to the specific case studies. Secondly, data is collected on the current production of the bio-based fertilising product, using available sources like statistics, reports by sector organisations, company specific data, other literature. Thirdly, a brief assessment is made of the maturity of the technology, providing insight in the size and number of installations, available suppliers, production capacities etc. Maturity is assessed based on commercial deployment, rather than the readiness of the technology. As the selection of value chains was directed towards currently best available technologies of bio-based fertiliser production, in many cases the production technology can be regarded mature, with limited challenges in the scale of technology in size. The differences between the selected value chains in maturity depends on the deployment of the technology across Member States, with a clear difference between a technology proven at full scale but still with a limited number of installations, or a technology widely deployed with numerous full-scale installations.

The focus of the fourth step is on the estimation of scale-up potential, e.g. the total possible future market of the bio-based fertiliser, by considering both the “feedstock-based production potential” and the “market-based production potential”.

The feedstock-based production potential is considering the feedstock available to produce the bio-based fertiliser (as described in D5.1), making assumptions on the share of feedstock that reasonably can be regarded available, and identifying unused feedstock potentials, for example, municipal bio-waste that is still collected together with other municipal waste, which could be a feedstock for compost production, if separate collection would have been applied.

The potential market size is estimated based on the most plausible direct applications of the bio-based fertiliser product. Next to the product properties and nutrient content, the status of a product as manure, RENURE or conventional fertiliser replacement and impact on applicability is considered and flagged if this status reduces the potential market size.

For each pathway, the final potential to scale up is quantified as follows. The **total potential (C)** is defined as minimum of the **feedstock-based potential (A)** and **market-based production potential (B)**

$$C = \min(A, B)$$

The **potential to scale up (E)** is calculated as:

$$E = C - D$$

where **D is the current production**.

The scale-up factor is calculated by dividing the potential to scale up (E) by the current production (D):

$$\text{Scale-up factor} = \frac{E}{D}$$

As a final step, for each pathway the most important barriers to scale up are briefly discussed, as input for the subsequent assessment within the FertiCovery project.

Unless stated otherwise, quantities refer to the EU27. Where installation counts or capacities from outside the EU27 are reported, this is indicated in the accompanying text or table caption, and such data are used to character technology maturity rather than to quantify EU production or potential.

1.5 This report

This report shows for each production pathway:

- An introduction with the brief description of the value chain
- Current production volumes and maturity of the technology
- Estimation of the feedstock-based production potential
- Description of plausible applications and estimation of the corresponding market size
- Calculation of the scale-up potential
- Description of barriers to scale up.

The report describes the following pathways:

- Composting of green waste and bio-waste that includes kitchen and garden waste (chapter 2)
- Anaerobic digestion (chapter 3)
- Digestate treatment to mineral concentrate by membranes and evaporation (chapter 4)
- Digestate treatment to potassium fertiliser (chapter 0)
- Struvite precipitation from wastewater (chapter 6)
- Stripping and scrubbing towards ammonium sulphate/nitrate (chapter 7)
- Slow pyrolysis to biochar (chapter 8)
- Hydrolysis (chapter 9)
- Plasma process to nitrogen-enriched manure slurry (chapter 10).

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2 Composting

2.1 Introduction

Bio-waste is defined in Article 3 of the Waste Framework Directive as "biodegradable garden and park waste, food and kitchen waste from households, offices, restaurants, wholesale, canteens, caterers and retail premises and comparable waste from food processing plants"[3]. As noted in D5.1, garden waste is not legally defined at EU level and generally means garden and park waste, or landscape maintenance waste. D5.1 quantifies bio-waste by material category, distinguishing food waste from garden waste. This report additionally distinguishes bio-waste by collection route, since the collection route generally determines which composting technology is applied. Separately collected garden waste is referred to here as green waste, and is generally composted in **windrow systems**. Mixed kitchen and garden waste requires **tunnel composting**, to meet requirements related to odour control. In general compost made of green waste has the highest quality.

Various designs of windrow composting can be found. One typical windrow composting design is open windrow composting with long rows with, say, a height of 3 m and a width of 6 m. Regular turning should be applied to maintain optimal oxygen conditions. Once the composting phase is completed, the material is screened to remove oversized fractions and produce a uniform compost product. An example is case study #8 "Open windrow composting of green waste". Some windrow composting systems use a semi-permeable membrane to cover compost windrows, creating a controlled "climate chamber" that accelerates aerobic decomposition. Examples are case studies #9 and #10 "Semi-permeable membrane windrow composting".

The tunnel composting process is a modular, completely enclosed and individually controllable or controlled technology, whereas the process runs fully automated by means of a positive aeration and forced irrigation. Tunnel composting is already viable with waste inputs from approx. 3,000 t/a but can be used equally for very high throughputs by simply increasing the number of modular units. It is suitable for the aerobic biological treatment of bio-waste, as well as for the further treatment of materials difficult to handle such as sewage sludge or digestate[4]. An example of tunnel composting is case study #7 "tunnel composting of bio-waste". Tunnel composting can be combined with anaerobic digestion as upstream process in a cascade treatment system. Examples are case study #1 "Dry anaerobic digestion and tunnel composting of bio-waste and green waste", technology #2 "Semi-dry anaerobic digestion and tunnel composting of bio-waste and green waste". A technology combining pre-treatment for the separation of bio-waste from impurities (non-compliant materials), anaerobic digestion and tunnel composting, is case study #3 "Wet anaerobic digestion and tunnel composting of bio-waste and green waste".

2.2 Current production and maturity

Current production

According to ECN (2022)[5] about 36 Mt/yr of separately collected bio-waste is composted in the EU27 in 2019, of which 26.6 Mt/yr is from municipal bio-waste. Table 2 provides a current overview of the different waste streams being composted.

Table 2: Amount of bio-wastes used for composting in the EU27 in 2019. Source: ECN (2022)[5]

Bio-waste streams as input for composting	% per source	Bio-waste (Mt/yr)
Green waste - separately collected	41%	14.8
Garden and food waste - co-collected	35%	12.6

[3] European Parliament and Council (2008) Directive 2008/98/EC, consolidated version of 16 October 2025. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02008L0098-20251016
[4] Strabag-umwelttechnik
[5] ECN (2022) ECN Data report 2022, compost and digestate for a circular economy, overview of bio-waste collection, treatment and markets across Europe. https://www.compostnetwork.info/wordpress/wp-content/uploads/ECN-rapport-2022.pdf

Food waste - separately collected	18%	6.48
Food and drink processing waste (C&I)	2%	0.72
Anaerobic digestate	1%	0.36
Other - separately collected	2%	0.72
Total	**100%**	**36.0**

ECN (2022)[5] also indicated that in 2019 17.4 Mt of compost is produced within the EU27, indicating an average conversion rate of 48%..

Technical maturity

According to ECN (2022)[5], within the EU27 about 3100 operational composting installations can be found. This number includes windrow, tunnel and any other type of composting plants. ECN (2022)[5] discloses that the median capacity of these composting plants is 8000 tonnes per year. Based on the 36 Mt of bio-waste processed in 2022, the average size of a composting plant is thus 11,612 tonnes per year. Starting with the data provided by ECN (2022)[5], BTG has estimated the average plant size per 25% percentile and subsequential production volumes, as shown in Table 3. It shows that it is likely that only 4% of bio-waste is processed by the 25% smallest plants, and in the order of 57% of the bio-waste is composted by the 25% of the largest plants.

Most likely, the separately collected green waste is processed with windrow composting in the smaller facilities, and the co-collected kitchen & garden and food waste and the other bio-waste streams in the larger tunnel composting plants. Due to the smell and hygienic requirements, windrow composting is only applied to separately collected green waste. However, in case the kitchen and garden waste requires more structural material, part of the separately collected green waste is expected to be processed in tunnel composting. In case of anaerobic digestion of co-collected garden and food waste followed by tunnel composting, substantial amounts of separately collected green waste may need to be added to ensure that the final compost product reaches the quality requirements[6].

Table 3: Estimation of the average size per composting plant per 25% percentile in the EU27.
Source: Estimation BTG starting from data of ECN (2022)[5]

		Production capacity (t/yr)				
Percentile of composting plants	**# of installations[a)]**	**Min[a)]**	**Max[a)]**	**assumed average[b)]**	**Production[b)] (Mt/yr)**	**% of production[b)]**
0 - 25% percentile	775	1	4,000	2,000	1.6	4%
25 - 50% percentile	775	4,000	8,000	6,000	4.7	13%
50 - 75% percentile	775	8,000	16,000	12,000	9.3	26%
75 - 100% percentile	775	16,000	94,000	26,451	20.5	57%
	3,100				**36.0**	**100%**

[a)] Source: ECN (2022)[5]; [b)] Estimation BTG. For the 0-25%, 25-50% and 50-75% percentile. BTG estimated the average production based on minimum and maximum production capacity of the percentile. For the 75-100% BTG assumed an average capacity of 26451 t/yr to derive to the total production of 36 Mt/yr.

ECN (2022)[5] indicates that 5% of the 3100 operational composting plants i.e. 155 plants combine anaerobic digestion with composting. As these installations are more complex, we assume that these plants are in the 75-100% percentile of larger plants with an average capacity of 26.5 kt/yr, which results in a roughly estimated input of 4.1 Mt/yr of anaerobically digested and composted bio-waste. A large part

[6] Source: BTG (2025) Interview BTG with compost processing company (anonymised)

of this capacity is located in Italy, where in 2017, already 47 AD & composting plants were installed with a total capacity of 3 Mt[7] per year (Italian Composting and Biogas Association 2017)[8].

It can be concluded that all types of composting have reached technical maturity since many years.

2.3 Feedstock-based production potential

According to our assessment in D5.1 (van der Voort et al., 2026)[9], based on combined Eurostat data[10], ECN (2022)[5] and BIC (2024)[11] in the EU27, about 95.1 (77.8 – 112.4) Mt of bio-waste was generated in 2022. Of these, 39.3 (28.1 - 50.6) Mt comprised green/garden waste, and 55.8 Mt comprised other bio-waste. As 100% capture of this potential will never be achieved, an operational potential, in line with best practices, based on data from long-standing and well-functioning schemes, in both rural and urban areas (BIC 2024), it is estimated that **maximally 85% of this theoretical potential** can be achieved. This means that the feedstock-based yearly generation potential of bio-waste is estimated around **80.8 Mt of bio-waste,** including 33.5 Mt of green waste.

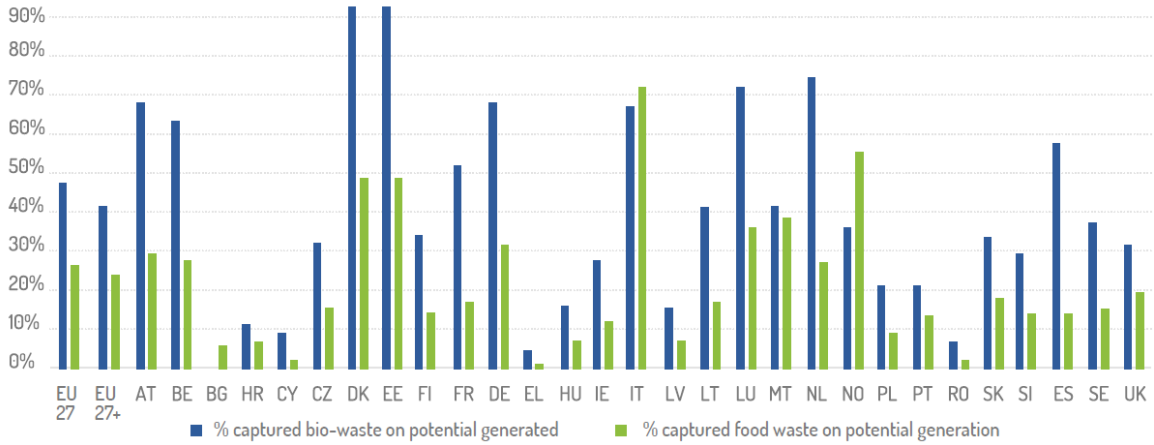


Figure 4: Comparison between theoretical potential / currently collected (food waste and bio-waste) in 2022. Source: BIC (2024)[11]

Figure 4 shows that the level of collection compared to the theoretical potential varies considerably between Member States (BIC 2024)[11]. The collection rates are still low in Eastern European countries such as Bulgaria, Hungary, Croatia, Poland and Romania, and Southern European countries such as Greece and Spain. Also, large countries such as France have substantial unused potentials for separate collection.

2.4 Applications and potential market size

Composting is the dominant way of processing separately collected municipal bio-waste. In Italy, anaerobic digestion prior to composting is the dominant processing pathway. However, in several Nordic countries such as Sweden, Norway, Finland and Estonia, anaerobic digestion without subsequent composting steps[12,13] is the most dominant bio-waste treatment method.

[7] 2.15 Mt/y from plants associated to the CIC, representing 70% of the total AD & composting capacity in Italy in 2017
[8] Italian Composting and Biogas Association (2017) Annual Report on Bio-waste Recycling, https://www.compost.it/wp-content/uploads/2019/08/Rapporto-CIC-2017-Eng-v-2.6-web-version.pdf
[9] Van der Voort and Vis (2025) Technical availability of feedstock supply, FertiCovery D5.1.
[10] Eurostat (2025) Municipal waste by waste management operations (env_wasmun). https://doi.org/10.2908/ENV_WASMUN
[11] BIC and Zero Waste Europe (2024) Bio-waste generation in the EU: Current capture levels and future potential, second edition. Bio-based Industries Consortium and Zero Waste Europe. https://biconsortium.eu/publication/bio-waste-generation-eu-current-capture-levels-and-future-potential-0
[12] (ECN 2026) Personal communication BTG with Steffen Walk and Aline Granjard of ECN on 29 May 2026
[13] https://www.municipalwasteeurope.eu/anaerobic-digestion-composting

There is data available on the application sectors of compost in the EU 27. ECN (2022) assumes that 49% of the compost produced in the EU27 is applied to agricultural soils. Data availability is better at national level. For example, Table 4 shows the distribution of compost produced in the Netherlands in 2023 to the different application sectors (Werkgroep Afvalregistratie 2025)[14].

Table 4: Distribution of compost produced in the Netherlands in 2023 to the different application sectors. (Source: Werkgroep Afvalregistratie (2025) Afvalverwerking in Nederland, gegevens 2023[14]).

Application sector	Compost (kt)	%
Agriculture, (greenhouse) horticulture, flower bulb cultivation, tree nurseries, fruit tree cultivation	460	73%
Potting soil sector	109	17%
Private sector (households)	12	2%
Landscapers: for intensive use of compost such as garden landscaping	12	2%
Landscaping (municipalities, sports field maintenance, garden centers, etc.)	8	1%
Civil engineering, civil engineering, contracting, etc.	7	1%
Sales via third party (application unknown but mainly agriculture and horticulture)	24	4%
Total	**632**	**100%**

In the Netherlands in 2023, in total 632 kton of compost was produced from 1523 kt of bio-waste, meaning that each tonne of bio-waste results in about 411 kg of compost. The main application sectors are agriculture (73%) (77% if sales via third party is included) and the potting soil sector (17%). The application of compost as component to replace peat in growing substrates, is expected to grow substantially in the next years. Peat excavation results in high emissions of CO_2, which can be reduced by replacing peat by compost. The quality requirements to the compost are high, meaning that peat replacement can realistically only partly be done by compost made of green waste, and in combination with other components as compost has a much higher nutrient value than peat. In 2022, in the Netherlands a "Covenant on the Environmental Impact of Potting Soil and Substrates"[15] to replace peat by several alternative products, including compost was established. In the same year Germany published its peat minimisation strategy[16]. This strategy states that, according to a survey by the German Horticultural Industry Association (IVG), approximately 11-12 million m^3 of substrates are currently produced annually in Germany. In 2021, alternative raw materials already accounted for around 4 million m^3, including about 1.6 million m^3 green compost (14% of total substrates and 42% of the alternative raw materials). This development results in an additional demand for compost made of green waste. Therefore, in general green waste compost is expected to be absorbed by various end users.

Compost from kitchen and garden waste is generally applied in the agricultural sector. In general compost is applied rather locally, within approx. 100 km from its production. International trade in compost is limited because regulatory frameworks differ per country. Compost that gets the CE-label under the FPR can be freely traded within the single market, thereby allowing cross-border shipments. It thus means that in case separate bio-waste collection is introduced in a certain country, efforts have to be made to convince regional final users to apply the compost for agricultural applications. Experience in other countries show there is currently a high compost demand in agriculture (ECN 2026). Given that there are still different perceptions of a green waste-based compost and a bio-waste-based compost which includes kitchen waste, it is important to ensure the compost is of good quality, and therefore quality standards and certifications are necessary. Examples are the quality requirements set by FPR (European

[14] Werkgroep Afvalregistratie (2025) Afvalverwerking in Nederland, gegevens 2023, https://www.rijksoverheid.nl/documenten/2025/01/31/afvalverwerking-in-nederland-gegevens-2023
[15] https://convenantpotgrond.nl/
[16] BMEL (2022) Torffrei gärtnern, Klima schützen Die Torfminderungsstrategie des BMEL, https://www.bmleh.de/SharedDocs/Downloads/DE/Broschueren/torfminderungsstrategie.html

CE label), ECN-QAS[17] (European Quality Assurance Scheme, i.e. the voluntary European compost quality standard of the European Compost Network ECN), and several national compost standards, such as RAL-GZ 251 (Germany)[18], RHP[19] (Netherlands), Keurcompost[20] (Netherlands), etc.

Given the good market perspective and quality of green-waste based compost, its market potential is estimated at 90% of its feedstock-based potential, i.e. 30.1 Mt of green waste corresponding to 14.9 Mt compost. This can largely be achieved by windrow composting. In case of the other bio-waste from (kitchen and garden waste), that generally requires tunnel composting, it is estimated that 70% of the feedstock-based potential can be realised as market potential, i.e. 33.1Mt bio-waste which corresponds to 16.2 Mt compost. The reason for the somewhat lower share of 70% is that in Nordic regions bio-waste is only anaerobically digested before used on soil and to reflect the somewhat higher efforts needed to establish end use markets in regions where bio-waste is not yet collected separately collected and applied on agricultural land. In total this gives a market potential of **63.3 Mt of bio-waste, and 31.2 Mt of compost**.

2.5 Scale-up potential

Table 5 shows out estimation of the scale-up potential of composting of bio-waste. As feedstock-based potential of 80.8 Mt of bio-waste has been taken, which is 85% of the total estimated bio-waste generation of 95.1 Mt. The market potential is somewhat lower, i.e. 63.3 Mt of bio-waste, and 31.2 Mt of compost. Compared to the **current compost production of 17.6 Mt** in the EU27 as estimated by ECN (2022), an additional growth of 80% is possible, compared to the current level of compost production, i.e. a **potential to scale up of 27.6 Mt bio-waste which corresponds to 13.6 Mt compost**. It is concluded that although compost is already applied widely within the EU27, it has still a large potential to grow.

Table 5: Estimation of the scale-up potential of compost production and application in the EU27 in 2030. Source: estimation BTG based on several sources as mentioned in the text.

	Bio-waste (Mt)	Compost (Mt)
A. Feedstock-based potential	**80.8**	**39.9**
Green waste	33.5	16.5
Other bio-waste	47.3	23.4
B. Market potential	**63.3**	**31.2**
Green waste (85% of feedstock-based potential)	30.1	14.9
Other bio-waste (70% of feedstock-based potential)	33.1	16.4
C. Total potential (minimum of A & B)	**63.3**	**31.2**
D. Current production	**35.6**	**17.6**
Green waste - separately collected	14.8	7.3
Garden and food waste - co-collected	12.6	6.2
Food waste - separately collected	6.5	3.2
Food and drink processing waste (C&I)	0.7	0.4
Anaerobic digestate	0.4	0.2
Other - separately collected	0.7	0.4
E. Potential to scale up (C - D)	**27.6**	**13.6**
Scale-up factor	0.8	0.8

[17] https://www.compostnetwork.info/ecn-qas/
[18] https://www.kompost.de/uploads/media/Quality_Requirements_of_digestion_residuals_in_Germany_text_01.pdf
[19] https://www.rhp.nl/en/product/compost
[20] https://keurcompost.nl/

2.6 Barriers to scale up

The main barrier to further scale up is the availability of separately collected municipal bio-waste, which strongly depends on the waste collection systems in place, and thus on national and European legislation. Article 11.2 of the Waste Framework Directive (WFD) requires Member States to take necessary measures designed to achieve, the preparing for re-use and recycling of municipal waste to be increased to 55% in 2025, 60% in 2030 and 65% in 2035 on mass basis. Moreover, Article 22 of the WFD requires Member States to ensure that by 31 December 2023, bio-waste is either separated and recycled at source, or is collected separately and not mixed with other types of waste. Despite this European legislation, by 2026 several Member States do not have separate bio-waste collection systems in place. A consortium organised by Zero Waste Europe[21], suggested that effective bio-waste collection is crucial for meeting the 65% recycling target, and suggests the EC to mandate targets for reducing the volume of bio-waste found in the mixed/residual (non-recyclable) waste.

2.7 Conclusions and recommendations

Composting of bio-waste is already widely applied and technically mature. Only when separately collected, bio-waste can be turned into high-quality compost. Depending on the feedstock, composting process, different qualities of compost can be produced with different end-user markets. Moreover, the resulting compost depends on the right process conditions (treatment time, irrigation, aeration, etc), and thus on the technical knowledge of the staff and the overall process engineering.

A first distinction can be made between compost made of green waste and compost made of mixed kitchen and garden waste. In general, green waste can be composted by windrow systems, and kitchen and garden waste requires tunnel composting. In general compost made of green waste has the highest quality, and application possibilities, with peat replacement in substrates as promising upcoming application.

It is estimated that yearly about 17.6 Mt of compost is produced from 36 Mt of bio-waste. Starting with a total volume of 95.1 Mt of bio-waste available within the EU, assuming that 80.8 Mt (85%) can be collected, and that compost markets are available for 63.3 Mt of bio-waste, i.e. 31.2 Mt of compost, there is a scale-up potential of an additional volume of 13.6 Mt of compost using 27.6 Mt of bio-waste.

The main barrier to further scale up is the availability of separately collected municipal bio-waste, which strongly depends on the waste collection systems in place[22]. Although EU legislation is in place, with the WFD requiring Member States to ensure that by 31 December 2023, bio-waste is either separated and recycled at source or is collected separately and not mixed with other types of waste, further strengthening and enforcement of this legislation is needed, to make the additional volumes of bio-waste available for composting.

[21] EBA (2025) Joint letter Waste Framework Directive. https://www.europeanbiogas.eu/wp-content/uploads/2025/06/Joint-letter-Waste-Framework-Directive.pdf
[22] See also LIFE BIOBEST - Guideline on the separate collection of bio-waste, https://www.compostnetwork.info/download/life-biobest-guideline-on-the-separate-collection-of-bio-waste/

3 Anaerobic digestion

3.1 Introduction

Anaerobic digestion (AD) is a biological process in which organic matter is broken down to produce biogas and digestate. While biogas is valorised as renewable energy carrier, digestate is the resulted nutrient-rich fraction co-produced during the digestion process, and it contains valuable organo-mineral nutrients, making it an appealing organic-mineral fertiliser.

Digestate can be applied to soil either untreated as direct output from AD plants (whole digestate) or after mechanical separation into solid and liquid fractions with different nutrient distribution thus each with its own agricultural benefits[23,24].

The liquid fraction, depending on the separation technology employed, represents between 70% and 97% of whole digestate and characterized by low content of dry matter (2-5%) and containing readily available ammonium nitrogen. The liquid fraction is the more immediately valuable fertilising product for local farmers, as it can be applied directly to nearby agricultural fields using existing slurry spreading equipment. Common strategies to optimise its transport and distribution include decentralised digestate storage near fields, underground pipelines and the use of large wheeled tankers (≥28 m^3) to supply farm-based storage or directly support spreading. The liquid fraction can also be further processed and upgraded, as discussed via some examples from case studies in section 4, 0 and 7. Separating the digestate into a liquid and solid fraction contributes to cost reduction and enables application at the most agronomically suitable times.

The solid fraction can be used as a soil conditioner and organic fertiliser. It is less significant in terms of weight and represents roughly 10–15% of whole digestate. It contains the more stable organic fraction thus supporting soil structure and its organic carbon pool along with organic nitrogen and organic phosphorus which are released slowly when applied into soil[25]. However, in contrast to the liquid fraction, the solid fraction can be more challenging to market and distribute, particularly in years when synthetic fertiliser prices are low and the economic incentive for farmers to use organic alternatives is reduced. Its higher dry matter content makes it more suitable than the liquid fraction for longer-distance transport.

This chapter focuses on the whole digestate and the solid fraction in fertilising products, as these are produced by some of the selected case studies. Five case studies have been selected that produce digestate from a range of feedstocks, as shown in Table 6.

- Case study #5 treats livestock manure, agricultural residues, bio-waste and industrial waste via AD, after which the digestate is separated in a liquid and solid fraction.
- Case study #6 treats bio-waste via anaerobic digestion, after which the digestate is separated in a liquid and solid fraction. The solid fraction can, after maturation, be applied as fertiliser.
- Case study #11 treats potato residues via anaerobic digestion. After separation of the digestate liquid fraction, the digestate solid fraction is recovered for use.
- Case studies #4 and #19 perform anaerobic digestion of respectively livestock manure and bio-waste and livestock manure. The digestate liquid fraction is treated further (see section 3 and 0) and the digestate solid fraction can be applied directly on agricultural land. Case study #4 produces about 40 kt of solid fraction a year, which is currently transported from the Netherlands to phosphate poor regions such as East Germany, Poland and northern France.

[23] EBA (2024) Exploring digestate's contribution to healthy soils. https://www.europeanbiogas.eu/wp-content/uploads/2024/03/Exploring-digestate-contribution-to-health-soils_EBA-Report.pdf
[24] Guidehouse Europe (2024) Biogases towards 2040 and beyond: A realistic and resilient path to climate neutrality. https://guidehouse.com/-/media/new-library/services/sustainability/documents/2024/biogases-towards-2040-and-beyond.pdf
[25] EBA (2026) Digestate in Europe the state of play in 2026. https://www.europeanbiogas.eu/publication/digestate-in-europe-the-state-of-play-in-2026/

- Case study #20 includes both the anaerobic digestion of livestock manure or agricultural residues via AD and, after solid-liquid separation, the further treatment of the digestate liquid fraction via membrane filtration to a mineral concentrate.

Table 6: Overview digestate producing case studies.

Case study	Feedstock	Solid fraction	Liquid fraction, unprocessed	Liquid fraction, further processed
#4	Pig manure	X		X
#5	Livestock manure, agricultural residues, bio-waste, industrial waste	X	X	
#6	Bio-waste	X	X	
#11	Potato residues	X	X	
#19	Bio-waste, livestock manure	X		X
#20	Livestock manure, agricultural residues	X		X

Case studies #1, #2 and #3 are composting technologies that treat the digestate solid fraction from bio-waste AD via tunnel composting to produce compost, as discussed in section 2.

This chapter focuses on the use of whole digestate and the digestate solid fraction as fertilising products. Liquid digestate fractions that are further upgraded into mineral concentrates or other recovered fertilising products are discussed in the dedicated technology chapters. The assessment therefore distinguishes between: (i) whole digestate directly applied as fertiliser, and (ii) separated digestate solid fraction applied as organic fertiliser or soil improver. Where relevant, liquid fraction volumes are reported to complete the mass balance, but they are not assessed as the main product in this chapter.

3.2 Current production and maturity

Current production

According to the EBA, **the total digestate production in Europe in 2024 amounted to 25 Mt (DM) or 450 Mt FM**[25]. Most digestate comes from agricultural feedstock[26] (of which around 60% is manure- based), organic municipal waste and industrial food waste account for 30% (DM) and sewage sludge represents 10% (DM). Aggregated data for Europe show that currently over 70% of all digestate is used directly as biofertiliser, while 20% is used as biofertiliser after upgrading, hence implying solid-liquid separation step[27].

The solid fraction part of whole digestate is reported per feedstock type (see Table 7), the **current production of solid fraction in 2024 range between 7-69 Mt (FM)** and 2-9 Mt (FM) respectively for agricultural feedstock and bio-waste. It should be noted that the figures are estimations, with a relatively large uncertainty due among others to large variability in water content due to differing AD processes.

[26] 'Agricultural feedstocks' sub-categories includes manure and other residues, such as straw, husks and cobs stripped of kernels of corn; sequential crops that are grown before of after the main crops, such as cover crops or catch crops and other fresh crops, or primary crops.
[27] EBA (2026) Statistical Report 2025.

Table 7: Estimated raw digestate, solid and liquid fractions in Europe in fresh matter (Mt/yr), based on combined biogas and biomethane production per feedstock category in 2024.
Source: EBA (2026)[25].

Feedstock	Raw digestate (Mt)	Solid fraction (Mt)	Liquid fraction (Mt)
Agricultural total	**230-236**	**7-69**	**161-229**
Manure	135-142	11-41	94-131
Energy/Mono crops	68-69	2-3	65-67
Sequential crops	10-12	2-3	7-10
Agricultural residues	12-15	3-4	8-12
Organic fraction of municipal solid waste	**17-18**	**2-5**	**12-16**
Industrial food and waste and industrial organic waste	**21-29**	**6-9**	**12-23**
Sewage sludge	**139-154**	**19-42**	**97-135**
Unknown	**5.6-6**	**1-2**	**4-5**
Total	**408-464**	**13-122**	**300-400**

Maturity

According to EBA, there are currently more than 21,000 biogas plants throughout Europe[28], indicating that AD technology has reached full technical maturity with commercial deployment throughout the EU.

3.3 Feedstock-based production potential

Based on D5.1, the theoretical feedstock availabilities for anaerobic digestion in the EU27 are shown in Table 8. These values cover the main input streams: livestock manure (pig and cattle), bio-waste (dominated by food waste), and sewage sludge. Poultry manure is excluded from the manure volume assumed to be available for anaerobic digestion, as it is not used as feedstock by any of the selected case studies. As explained in more detail in D5.1, poultry manure is rarely mono-digested, due to its high dry matter content, low carbon to nitrogen ratio, the non-digestible bedding fraction of the broiler litter and the ammonia build-up during digestion, which can eventually stop the AD process and methane production (Ngo et al, 2022)[29].

To contextualise the scale of untapped potential: of the total estimated livestock manure production in the EU of approximately 1.0-1.8 billion tonnes per year, only 10-17% currently enters anaerobic digestion, producing approximately 135 Mt of manure-based whole digestate annually[25]. Similarly, of the total estimated bio-waste generation in the EU of approximately 68-120 Mt per year, only 8.5-15% currently goes to anaerobic digestion[5].

The EBA statistical report confirms that the agricultural residues category specifically refers to straw, husks and cobs stripped of kernels of corn, sequential crops, that are grown before or after the main crop primary crops as cover crops or catch crops (which reduce the chemical input into the soil and restore soil health); and other fresh crops, or primary crops.

Since sequential crops and primary crops are not considered secondary raw materials, these fall out of scope for FertiCovery. Additionally, within the agricultural residues category, straw and other lignocellulosic residues typically present greater challenges compared to food waste, manure and more readily substrate, although manageable usually by pretreatment and co-digestion to achieve good performance. These are therefore not considered as potential feedstocks.

[28] EBA (2026) About biogas and biomethane. https://www.europeanbiogas.eu/our-dna/about-biogas-and-biomethane/
[29] Ngo et al. (2022) Improving bioenergy production in anaerobic digestion systems utilising chicken manure via pyrolysed biochar additives: A review. Fuel, vol. 316, pp. 123374. https://doi.org/10.1016/j.fuel.2022.123374

To estimate the feedstock-based production potential of the digestate solid fraction, two conversion steps are applied per feedstock stream. First, a feedstock to digestate conversion factor is applied, reflecting mass loss primarily through biogas generation during digestion, see Table 8. This results in **a total digestate potential of 1,062 Mt FM across EU**, if all the listed feedstocks from the case studies in Table 6 are treated by AD. As visible, livestock manure dominates the theoretical potential, due to the very large volumes of manure available.

For comparison, current digestate production volumes per stream are also provided, derived from EBA (2026) and ECN (2022). This indicates that **only a small fraction of the theoretical potential is currently being realised**. It should be noted that this estimate represents the theoretical maximum based on feedstock availability, assuming the listed feedstocks are collected and digested. In practice, a significant share of manure in particular is managed without AD by directly applying to the land.

Table 8: Feedstock availability, calculated digestate potential in EU27 and current digestate production.

Feedstock	Theoretical feedstock availability in EU27, midpoint (Mt FM)[a]	Feedstock to digestate conversion factors	Total digestate potential (Mt)	Current digestate production (Mt)
Livestock manure (pig and cattle)	1,062	92%	977	135-142[b]
Bio-waste (incl. food waste)	95	90%	86*	17-21[b]
Total			**1,063**	

a) D5.1, manure collection potential total; b) EBA (2026); c) ECN (2022), assuming 90% conversion to digestate; * assuming 90% conversion to digestate.

Subsequently, solid fraction percentages per stream are applied to estimate the solid fraction production potentials after solid-liquid separation of the digestate. The mass of the solid fraction differs and is highly dependent on the type of AD, the process conditions, and the feedstock. Therefore, a range of solid fraction mass is taken per feedstock type[30]. Thus, the indicative **feedstock-based potential of the solid fraction of digestate is estimated at 67-134 Mt FM**.

Table 9: Calculated solid and liquid fraction feedstock-based potentials in EU27.

Feedstock	Total digestate potential (Mt FM)	Solid fraction (% of total)	Solid fraction (Mt FM)	Liquid fraction (Mt FM)
Livestock manure	977	6-12	59-117	860-918
Bio-waste (incl. food waste)	86	10-20	9-17	68-77
Total	**1,063**		**67-134**	**928-995**

It should be noted that these solid and liquid fraction feedstock-based potentials are based on the assumption that all whole digestate is separated.

3.4 Applications and potential market size

The primary application of the digestate solid fraction is as an organic fertiliser and soil improver for direct land application. During solid-liquid separation, the solid fraction concentrates phosphorus and organic

[30] Drosg et al. (2015) Nutrient recovery by biogas digestate processing. *IEA Bioenergy Task 37*. https://www.ieabioenergy.com/wp-content/uploads/2015/08/NUTRIENT_RECOVERY_RZ_web2.pdf

carbon and nitrogen, whilst the liquid fraction contains the majority of the mineral nitrogen (in the form of ammonium)[30].

The market potential can be expressed in terms of synthetic fertiliser replacement potential of the total digestate, as reported by EBA (2026). According to EBA (2026), currently 8.3 Mt of nitrogen-based fertilisers are consumed yearly. Following the reported digestate nitrogen content of 1.7 Mt[27], this indicates that digestate has the potential to replace 17% of nitrogen-based fertilisers, as shown in Table 10. With the projected growth, according to EBA, digestate could substitute over 65% of synthetic nitrogen in the EU by 2040.

The phosphorus replacement potential is even more substantial. At current production levels, the digestate nutrients could already replace 26% of the synthetic phosphorus fertilisers, rising to 84% in 2040.

Table 10: Replacement potential of digestate relative to EU27 synthetic mineral fertiliser consumption, for 2024 and 2040, as reported by EBA (2026)[25].

	Nutrient content (Mt)		Synthetic fertiliser replacement potential	
	2024	2040	2024	2040
Nitrogen (N)	1.70	5.4	17%	65%
Phosphorus (P)	0.32	1.0	25%	84%
Potassium (K)	0.18	0.6	7%	25%

It should be noted that digestate does not always substitute chemical fertilisers, especially in the case of livestock manure or agricultural residues, which otherwise also would have been used directly as fertiliser in the agricultural sector. The nutrient contents are therefore better described as “equivalents” than as “substitutes”.

To calculate the digestate market potential in digestate volumes, the average percentages of nutrients in digestate can be calculated (nutrient content/total digestate production, so for nitrogen: 1.7/411). This results in nutrient contents in whole digestate of nitrogen, phosphorus and potassium of respectively 0.4%, 0.1% and 0.04%. Based on the EU nutrient demands and the just calculated nutrient content percentages, the whole digestate demand can be calculated (Table 11). This results in a **whole digestate theoretical market demand of 2,007 Mt N, 1,156 Mt P and 5,708 Mt K**.

Table 11: Whole digestate theoretical market demand in the EU27 in 2024, calculated from EU synthetic mineral fertiliser consumption and the average nutrient content of whole digestate.

Whole digestate	EU synthetic fertiliser consumption (Mt)	Nutrient content in whole digestate	Whole digestate theoretical market demand in 2024 (Mt)
Nitrogen (N)	8.3	0.4%	2,007
Phosphorus (P)	0.9	0.1%	1,156
Potassium (K)	2.5	0.04%	5,708

These figures indicate that in theory nutrient demand is not the limiting factor for digestate uptake at EU level. They represent solely a potential, not a realisable market. Whether the calculated demand can be met in practice depends on factors like the suitability for agronomic purposes, the balance between nutrients in digestate and crop requirements, transport distances between production and application. These aspects have not been assessed in this report and would require a separate analysis.

The replacement potentials and theoretical market demands from Table 10 and Table 11 cover whole digestate. The nutrient content in the solid and liquid fractions separately is highly dependent on the solid-liquid separation method (e.g. screw press, decanter centrifuge) and the use of coagulants / flocculants[27]. Phosphorus largely accumulates in the solid fraction (1-50%, depending on separation method and coagulant use), while potassium (95%) and ammonium nitrogen (80-90%) are mostly retained in the liquid fraction. Organic nitrogen distributes differently, with approximately 80% remaining in the solid fraction[23]. The separation technology also influences the nutrient contents, for example, with a decanter centrifuge,

phosphorus partitioning to the solid fraction ranges from 51-71%, whereas with a screw press, this is significantly lower at approximately 29%[30,31,32].

To estimate the digestate solid fraction market potential, the following separation assumptions are applied: phosphorus 50% to solid fraction (as described above, the share of phosphorus ending up in the solid fraction varies significantly by separator type; 50% is applied here as a central estimate for centrifuge based separation with coagulant, consistent with upper end of Decorte et al. 2024 range); total nitrogen 30% to solid fraction (a conservative estimate between the ammonium-N that is mostly in the liquid fraction and organic-N in the solid fraction, in line with literature[32]; and potassium 5% to solid fraction[23]. Applied to current digestate production nutrient contents (1.70 Mt N, 0.32 Mt P, 0.18 Mt K), this gives an average solid fraction nutrient content of 0.51 Mt N, 0.16 Mt P and 0.009 Mt K at current production of 25 Mt FM solid fraction, see Table 12.

Table 12: Nutrients in digestate solid fraction current production in the EU27.

Solid fraction	Nutrients in current production digestate (Mt)	Nutrients to solid fraction (%)	Current production of nutrients in solid fraction (Mt)
Nitrogen (N)	1.7	30	0.51
Phosphorus (P)	0.32	50	0.16
Potassium (K)	0.18	5	0.01

Based on the EU nutrient demands (Table 11) and these nutrients in the solid fraction, the solid fraction digestate theoretical market demand is calculated in Table 13. It should be noted that nutrient concentrations in the digestate solid fraction vary significantly by feedstock and processing method. The table values represent averages across all feedstock streams and are used to estimate the theoretical market demand. These calculations result in a **solid fraction theoretical market demand of 402 Mt N, 139 Mt P and 6,861 Mt K**.

Table 13: Solid fraction digestate theoretical market demand in the EU27 in 2024, calculated from EU synthetic mineral fertiliser consumption and the average nutrient content of whole digestate.

	Nutrient content in solid fraction digestate[a]	EU synthetic fertiliser consumption (Mt)	Solid fraction digestate theoretical market demand in 2024 (Mt)
Nitrogen (N)	2.1%	8.3	402
Phosphorus (P)	0.6%	0.9	139
Potassium (K)	0.04%	2.5	6,861

a) Calculated based on the current production of nutrients in solid fraction divided by the total solid fraction production.

3.5 Scale-up potential

The EU27 could substantially expand digestate use (Table 14). Most of the potential lies in implemented collection and digestion of available feedstocks and, especially for the solid fraction, in increasing separation. Whole digestate production could rise from 450 to 1,063 Mt FM (scale-up factor 1.4), the solid fraction could increase from 50 to 101 Mt FM (scale-up factor 1.0).

[31] Cathcart et al. (2023) Optimising mechanical separation of anaerobic digestate for total solids and nutrient removal. *Journal of Environmental Management*, vol. 345, pp. 118449. https://doi.org/10.1016/j.jenvman.2023.118449
[32] Tambone et al. (2017) Solid and liquid fractionation of digestate: Mass balance, chemical characterization, and agronomic and environmental value. *Bioresource Technology*, vol. 243, pp. 1251-1256. https://doi.org/10.1016/j.biortech.2017.07.130

Overall, around 613 Mt FM (whole digestate) and 51 Mt FM (solid fraction) represent untapped annual production potential, reflecting a mature but still expandable AD sector, driven mainly by manure use, bio-waste and residue treatment, and more widespread solid–liquid separation[33].

It should of course be noted that whole digestate application and digestate solid fraction application represent two alternative routes for the same input feedstocks, not complementary ones. A biogas plant that applies whole digestate directly to land does not produce a separable solid fraction, and vice versa. The choice between routes will depend on local agronomic conditions, nutrient surplus zones and regulatory requirements. The scale-up potentials in this chapter for whole digestate and digestate solid fraction should therefore be interpreted as alternative scenarios rather than additive ones.

Table 14: Scale-up potential summary whole digestate and solid fraction digestate in the EU27.
Source: estimation BTG based on several sources as mentioned in the text.

	Whole digestate (Mt)	Digestate solid fraction (Mt)
A. Feedstock-based potential	**1,063**	**101**
- Livestock manure	977	88
- Bio-waste	86	13
B. Market potential		
- Nitrogen	2,007	402
- Phosphorus	1,156	139
- Potassium	5,708	6,861
C. Total potential (minimum of A & B)		
- Nitrogen	1,063	101
- Phosphorus	1,063	101
- Potassium	1,063	101
D. Current production	**450**	**50**
E. Potential to scale up (C - D)	613	51
Scale-up factor	1.4	1.0

3.6 Barriers to scale up

Anaerobic digestion is a technically mature and widely deployed technology, however, digestate market remains underdeveloped and several barriers remain for further up-scaling of digestate and digestate solid fraction as fertilising products.

Feedstock availability and mobilisation

- Most of the theoretical feedstock potential comes from livestock manure, but a large share is still spread directly on fields without going through AD.
- Municipal bio-waste potential depends on how well separate collection systems work.

Processing, storage and transport logistics

- Whole digestate and the liquid fraction have a high water content and low nutrient concentration, making transport over distances greater than approximately 10 km

[33] Whole digestate use and solid fraction use are two alternatives' pathways from the same feedstocks. Therefore, a plant either applies whole digestate or separates it into fractions, depending on local conditions and regulation, (i.e local agronomic conditions, nutrient surplus zones etc.) so their scale-up potentials must be treated as separated scenarios and not obviously summed up.

economically unattractive unless a clear nutrient surplus and receiving demand exist. Long distance trade exists (e.g. Netherlands to Germany, Poland and France) but remains limited to a small share of total volumes (<3%).
- Further scale-up of the solid fraction requires more AD plants to invest in solid-liquid separation equipment.

Regulatory complexity

- Digestate is included in EU and national legislation on waste, animal by-products and fertilisers. Depending on the feedstock, treatment process, intended use and marketing route, digestate may be regulated as different type of products. This creates uncertainty for producers and users, particularly for cross-border trade.
- Under the Nitrates Directive, manure-based digestate often still counts as manure, limiting its use vs mineral fertilisers

Market structure and pricing

- A central and underlying barrier is the structural undervaluation of digestate in the current market. In several countries, specifically where larger centralised AD plants operate, digestate is returned to farmers free of charge as informal compensation for the feedstock they originally supply to the plant. While this gives farmers a cost-saving alternative to synthetic fertiliser, it means digestate is valued primarily as a waste-disposal arrangement rather than priced according to its actual agronomic value[25].
- This zero or low pricing creates a market distortion that discourages investment in quality improvement, further processing and upgrading, since biogas operators absorb the costs of digestate management without a competitive market price to recover them. This also creates a lock-in between individual farms and their associated biogas plant, weakening competition and innovation in digestate processing[25].

Farmer acceptance

- Variable composition makes digestate less predictable than mineral fertilisers, reducing confidence in its use, when concerns exist regarding contamination.
- The nutrient ratio in digestate is determined by the feedstock and might not match the crop requirements. Digestate is relatively rich in nitrogen and phosphorus and poor in potassium compared with average EU NPK fertilisers, so an application rate that meets one nutrient requirement will in all probability over or under supply the others. Supplementary (mineral) fertiliser, and/or further processing of the digestate (see chapter 4, 5 and 7) might therefore still be needed.
- Application rates are in addition constrained by regulatory limits under the Nitrates Directive and national regulations, which can be reached before crop nutrient requirements are met.

3.7 Conclusions and recommendations

Anaerobic digestion is a mature and widely applied technology for treating organic secondary raw materials while producing biogas and digestate therefore from a scale-up perspective, the technology itself does not represent the main bottleneck.

There is large, untapped feedstock potential for digestate, especially from livestock manure availability, and separately collected municipal bio-waste. Future work could explore the potential of additional feedstock streams for anaerobic digestion, such as industrial organic sludges, which were outside the scope of this report but could contribute to the feedstock-based potential. The analysis indicates that the market demand for nitrogen and potassium is theoretically large enough to absorb the estimated feedstock-based potential for whole digestate. The overall scale-up potential is substantial, namely 613 Mt for whole digestate and 51 Mt for the digestate solid fraction. Whole digestate application and solid fraction production should be seen as alternative routes for the same input feedstocks, not as additive scale-up pathways. Scaling depends on removing barriers as nitrogen and phosphate sensitive areas, digestate management becomes a bottleneck due to distance as a main cost driver and the regulatory framework especially in nutrient surplus areas can be a major barrier itself.

4 Digestate treatment to mineral concentrate by membranes and evaporation

4.1 Introduction

Digestate liquid fraction upgrading to nutrient concentrates is a technology pathway that can concentrate nitrogen and potassium from the liquid fraction of digestate into a liquid fertiliser product. Three case studies use membranes and/or evaporation to concentrate these nutrients. Although the three case studies use different treatment configurations, they all produce a liquid fertilising product from digestate with NPK concentrations in the same order of magnitude (see Table 15). The products are therefore relevant for the same broad market segment: liquid fertilisers that could partially replace synthetic mineral fertilisers, especially nitrogen and potassium fertilisers, through land application or fertigation/irrigation systems.

Table 15: Case study products characteristics producing liquid nutrient concentrates.

Case study and product	N (%)	P (%)	K (%)
#4 Mineral concentrate	0.8	0.05	0.8
#19 Evaporator concentrate	1.3	0.2	2.2
#20 Organo-mineral concentrate	1.1	0.1	0.17

The main difference between the case studies lies in the production pathway and product positioning.

- Case study #4 treats the effluent from an aerobic stabilisation step directly by **reverse osmosis** (RO), producing a **mineral concentrate** that is **mixed with animal manure** and applied to agricultural land.
- Case study #19 **evaporator concentrate** and solid blends are market products, the rest of the system is designed for internal recycling and efficiency. The process separates digestate into fertilising products and water recycling stream. The liquid fraction is **aerobically stabilised**, followed by **evaporation**, producing a nutrient rich concentrate that is traded as fertiliser to the Netherlands or mixed with dried solid fraction and exported to France. The evaporation produces process water that is treated via RO, but this concentrate is recirculated to the aerobic treatment.
- Case study #20 applies an **ultrafiltration membrane** bioreactor to the liquid digestate fraction, producing a **liquid organo-mineral fertiliser** as the **ultrafiltration retentate**. For assessing market demand and scale-up, these cases are assessed together in this section as liquid nutrient concentrates from digestate. Where relevant, differences in production pathways are distinguished.

All three case studies consist of a single installation with an anaerobic digester upstream of the digestate treatment process, as summarised in Table 16.

The mineral concentrate produced via reverse osmosis is particularly well-positioned as a synthetic fertiliser substitute. It is high in nitrogen and potassium, making it suitable for nitrogen potassium requiring crops like potatoes, maize, lettuce and leek, and it is also used on dairy farms. The regulatory context of this product has evolved in the past decade. In the Netherlands, a national pilot programme for mineral concentrates from manure treatment has been operational since 2015[34]. Under this pilot, 13 companies have invested in installations producing mineral concentrates from manure treatment, with 17 installations participating by 2020, collectively treating manure into synthetic fertiliser replacements for a

[34] Hoeksma et al. (2021) Composition of mineral concentrates: Results of monitoring installations of the Pilot Mineral Concentrate in 2019-2020. Wageningen Livestock Research, Report 1295. https://doi.org/10.18174/541577

maximum of 20,000 ha of agricultural land[35]. By 2021, this resulted in a total of 3,000 ton of nitrogen usage as mineral concentrate outside the usage standard for animal manure. Results from the pilot show that RO-based mineral concentrate can be characterised mostly as a mineral fertiliser with N and K as the main nutrients, though some installations did not meet all RENURE mineral concentrate quality criteria, mainly the TAN/Total-N ratio (≥ 0.90).

Table 16: Overview of case studies producing nutrient concentrate from digestate.

Case study and product	Digestate source	Technology (after digestate solid-liquid separation)	Production capacity (kt/yr)
#4 Mineral concentrate	Pig manure	Stabilisation and reverse osmosis	100
#19 Evaporator concentrate	Manure; sludge from industrial WWTPs and other bio-wastes; glycerine and molasses	Stabilisation and evaporation	5.8
#20 Organo-mineral concentrate	Pig and chicken manure; slaughterhouse waste/ meat processing byproducts; food leftovers; expired food; cheese whey	Ultra-filtration membrane bioreactor	~5-10

At EU level, the regulatory landscape shifted when the EU Nitrates Committee formally agreed the RENURE framework, recognising three product types as RENURE fertilising products: ammonium salts from gas purification, mineral concentrates from reverse osmosis, and struvite. This agreement means that RO-based mineral concentrate, as produced by case study #4, can be applied above the 170 kg N/ha manure application limit across all EU member states, once implemented into national legislation. Evaporator concentrate (case study #19) and UF retentate (case study #20) are not explicitly recognised under the current RENURE framework, though they may qualify if they meet some criteria on a case-by-case basis.

The quantitative assessment in this chapter covers mineral concentrate produced via reverse osmosis, corresponding to case study #4. This applies to the feedstock-based potential, the market potential and the resulting scale-up potential.

4.2 Current production and maturity

Current production

The production of liquid nutrient concentrates from digestate via RO, evaporation and membrane filtration is a commercially available technology, with the Netherlands in all probability the frontrunner in Europe due to its longstanding national pilot programme for mineral concentrates.

17% of the operational manure treatment companies in the Netherlands extract a liquid concentrate from the liquid fraction of manure or digestate from manure, producing 3.2 kt nitrogen, 0.1 kt phosphate, or 464 kt total in 2024[36]. As of 2025, there are 27 companies in the Netherlands producing mineral concentrates, indicating broader development beyond the formal pilot programme, which has been running since 2015 within which a maximum of ten producers were allowed to apply their produced mineral concentrate at up to 80 kg N/ha above the standard 170 kg N/ha animal manure application limit.

Commercial or near-commercial production of comparable nutrient concentrates from digestate exists in Flanders (Belgium), Italy and Greece, but EU-level production statistics do not seem to exist[37,38].

[35] Buning (2015) Mineralenconcentraat niet op eigen benen. Pig Business. https://edepot.wur.nl/365909
[36] Nederlands Centrum Mestverwaarding (NCM) (2025) Landelijke rapportage en inventarisatie export en verwerking dierlijke mest 2025. https://www.mestverwaarding.nl/storage/article/files/2025/11/691ed967c3e03.pdf
[37] VCM (2020) Flemish biobased fertilizers recovered from manure complying to the RENURE-criteria. p.38 https://cdn.digisecure.be/vcm/202153102710731_20210208-renure-informationdocument-online.pdf
[38] Herrera et al. (2023) Pig slurry management producing N mineral concentrates: a full-scale case study. *ACS Sustainable Chemistry & Engineering,* vol. 10, no. 19, pp. 7309-7322. https://doi.org/10.1021/acssuschemeng.2c07016

For the Netherlands, NCM (2025) reports 0.46 Mt of liquid concentrate produced from the liquid fraction of manure and manure digestate in 2024, which is taken as the Dutch production volume. In Flanders, the deployment is understood to follow that in the Netherlands closely, and in 2024, three installations were operational that produced mineral concentrate by reverse osmosis, together producing 0.04 Mt/yr[39]. Elsewhere in the EU, individual full-scale installations are documented, like in Italy and Greece, but no production data is available at Member State or EU level. **The current EU27 production is therefore estimated at 0.5 to 0.8 Mt**, where the lower bound reflects the actual reported Dutch and Flemish volumes in 2024, and the upper bound allows for unreported production elsewhere and for installations not captured in national inventories.

Maturity

As mentioned above, commercial or near-commercial production of comparable nutrient concentrates from digestate exists in the Netherlands, Flanders (Belgium), Italy and Greece. Liquid nutrient concentrates are thus a **commercially proven technology already scaling in the Netherlands**, with EU-wide expansion expected through RENURE implementation.

4.3 Feedstock-based production potential

In practice, mineral concentrate production via RO is predominantly based on pig manure as feedstock. This is reflected in the Dutch pilot programme, where 93% of production is located in intensive pig farming regions[36], the Nutriman project information on case studies[40], and case study #4 and #20 data. The dominance of pig manure in this treatment technology as feedstock reflects is relatively high nitrogen concentrations compared to cattle slurry[41].

However, this technology is not exclusively limited to pig manure or pig manure digestate. Case study #19 processes a mixed feedstock including manure, industrial WWTP sludge, bio-waste and glycerine, while case study #20 processes pig and chicken manure alongside slaughterhouse waste and food processing residues. For the feedstock-based potential calculation, pig manure is used as the primary feedstock given its dominant role in current production, whilst acknowledging that the potential might be larger due to other feedstocks that contribute in practice.

[39] VCM (2024) RENURE: REcovered Nitrogen from maNURE. Vlaams Coördinatiecentrum Mestverwerking. https://cdn.digisecure.be/vcm/20251289444335_20250122-overzicht-renure.pdf
[40] Nutriman (n.a.) Mineral concentrate from pig/cattle slurry using belt press sieve and reverse osmosis processing. https://nutriman.net/farmer-platform/product/id_520
[41] FAO (n.a.) List of commonly used organic manure. https://www.fao.org/fileadmin/user_upload/affris/docs/Rohu_Labeo/English/table_5.htm

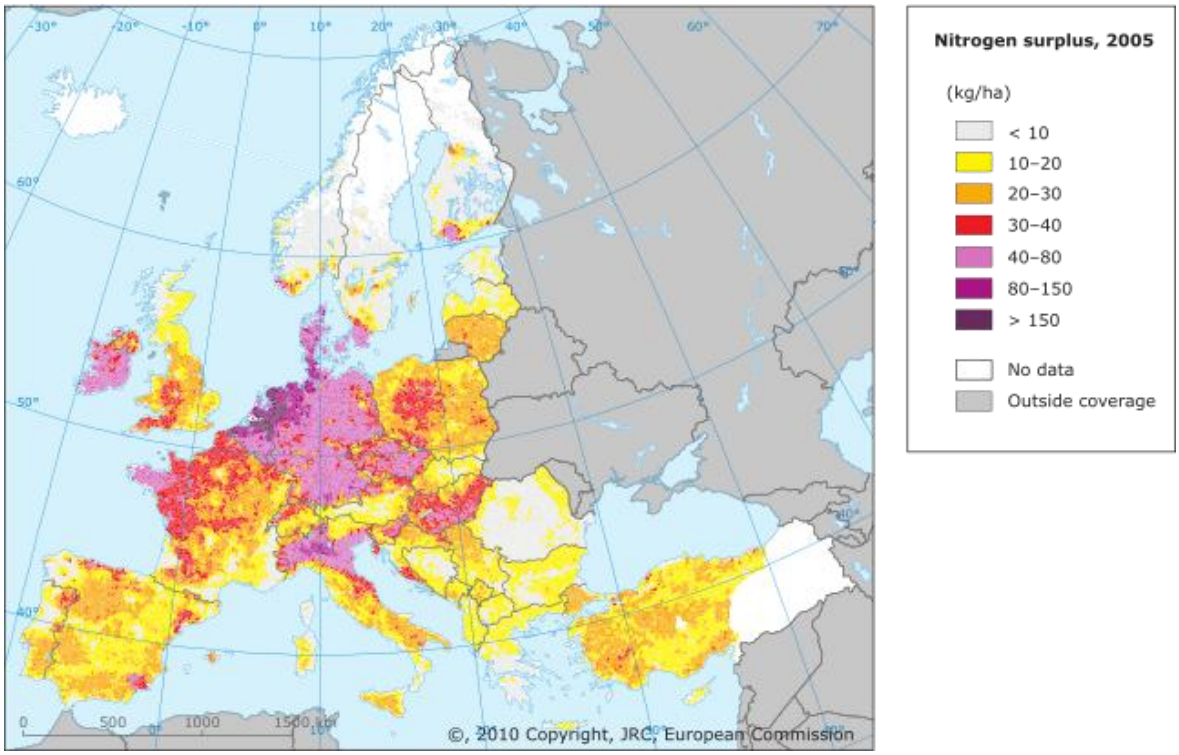


Figure 5: Estimated nitrogen surplus for the year 2005 across Europe. Source: JRC (2010)[42].

Based on D5.1, pig manure availability in the EU27 is estimated at 289 Mt. Farmers and regions with sufficient land will apply the manure directly and are likely to not have any incentives to invest and use RO treatment. An EU-wide pig manure surplus figure is not available in literature. Therefore, it is assumed that pig manure processing via RO is mainly relevant in livestock-dense regions, that match with regions with high critical nitrogen input exceedance: Belgium (Flanders), the Netherlands, and at a local level Italy, France (Brittany), Spain and Portugal, and in a lesser extent Denmark, UK, a few counties of Ireland and Southern Germany[43,44]. This is also visible in Figure 5, with a visualisation of the estimated nitrogen surplus across Europe. For example, in Flanders, 49% of produced pig manure is a surplus[45].

The surplus fractions of pig manure per country in Table 17 are derived as follows. For the Netherlands, 94% of pig farms produce more manure than they can use themselves[46], which reflects the high livestock density relative to the available agricultural land. For Italy, France, Spain and Portugal, a surplus fraction of 20% is assumed. These countries contain nitrogen surplus regions, but also large agricultural areas where manure can be applied directly. The 20% is an indicative estimate reflecting that surplus is regionally concentrated rather than nationwide, which is consistent with the geographic distribution shown in Figure 5. For Denmark, Ireland, Germany and Poland, a surplus fraction of 10% is applied, also informed by the distribution of nitrogen surplus as shown in Figure 5. Both the 20% and the 10% are assumptions made for this assessment in the absence of country-level surplus data, in contrast to the fractions for Belgium and the Netherlands, which are taken from literature. Together, the assumed

[42] JRC, European Commission (2010) Estimated nitrogen surplus across Europe, 2005. https://www.eea.europa.eu/en/analysis/maps-and-charts/estimated-nitrogen-surplus-across-europe-2005?activeTab=a7caf3b5-7254-4a24-8919-693d4115158b

[43] European Commission (2007) COM(2007) 120 final. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52007DC0120

[44] De Vries et al. (2022) Impacts of nutrients and heavy metals in European agriculture. ETC-DI. https://www.eionet.europa.eu/etcs/etc-di/products/etc-di-products/impacts-of-nutrients-and-heavy-metals-in-european-agriculture-current-and-critical-inputs-in-relation-to-air-soil-and-water-quality

[45] Vingerhoets et al. (2023) Detailed nitrogen and phosphorus flow analysis, nutrient use efficiency and circularity in the agri-food system of a livestock-intensive region. *Journal of Cleaner Production*, vol. 410. https://doi.org/10.1016/j.jclepro.2023.137278

[46] Sikkema (2026) Peddling manure. WUR. https://www.wur.nl/en/longread/peddling-manure

fractions account for 35 Mt of the 61 Mt total surplus. The estimate is therefore sensitive to these assumptions, and the estimated pig manure surplus should be seen as a central estimate. Whilst these countries have livestock-dense regions, the overall surplus fraction is lower because there is a lot of available land for direct application. For all other EU countries, it is assumed that pig farming in these regions is generally less intensive and manure surpluses are not a structural problem.

Table 17: Estimated pig manure surplus fractions per country.

Country	Surplus fraction	Pig manure surplus (Mt)
Belgium	49%[45]	6
The Netherlands	94%[46]	21
Italy, France, Spain, Portugal	20%	25
Denmark, Ireland, Germany, Poland	10%	10
Other countries	0%	0
Total		**61**

These assumptions are supported by independent country-level nitrogen balance data[47], which shows a positive nitrogen balance (manure-N exceeding crop uptake without mineral fertiliser) in Belgium (+86 kg N/ha), the Netherlands (+74 kg N/ha), Italy (+15 kg N/ha), Portugal (+37 kg N/ha) and Spain (+14 kg N/ha), consistent with the surplus countries identified above. It should be noted that national-level nitrogen surplus figures do not cover regional variation. Surpluses are typically concentrated in specific livestock-dense regions within a country (e.g. Flanders in Belgium, Brittany in France), rather than being evenly distributed, and are further influenced by the complexity of soil-plant-microbial interactions, carbon dynamics, and the diversity of farming systems across Europe. The national averages used in this analysis should therefore be interpreted as indicative rather than precise.

Using these surplus fractions and the pig manure production per country from D5.1 gives a total estimated **pig manure surplus production of 61 Mt**.

Using the conversion of pig manure to mineral concentrate of case study #4[48], gives a total estimated **mineral concentrate feedstock-based potential of 24 Mt**, as shown in Table 18.

Table 18: Feedstock-based potential mineral concentrate in the EU27.

Feedstock	Theoretical feedstock availability in EU27, midpoint (Mt)	Conversion [a)]	Total mineral concentrate potential (Mt)
Pig manure	61	40%	**24**

a) Calculated based on case study #4 data (250 kt manure input; 100 kt mineral concentrate production)

4.4 Applications and potential market size

The mineral concentrate produced via RO can be applied as a liquid NK fertiliser on agriculture land, substituting for nitrogen and potassium fertilisers. The phosphorus content in mineral concentrates is generally low (see Table 15) and the product will therefore not have a significant agronomic value as a phosphorus fertiliser[49]. Because the nitrogen and potassium in the mineral concentrate are largely plant-

[47] Table 8 in EBA (2026) Digestate in Europe the state of play in 2026. https://www.europeanbiogas.eu/publication/digestate-in-europe-the-state-of-play-in-2026/
[48] Which corresponds to the source NCM (2025) Landelijke rapportage en inventarisatie export en verwerking dierlijke mest 2025. https://www.mestverwaarding.nl/storage/article/files/2025/11/691ed967c3e03.pdf, who report a conversion of 33-42% on average from manure to mineral concentrate.
[49] Velthof (2015) Mineral concentrate from processed manure as fertiliser. Wageningen, Alterra report 2650. https://edepot.wur.nl/352930

available, its fertilising value is higher than that of unprocessed manure[50]. The product is thus more a supplementary nitrogen and, in a less significant amount, potassium fertiliser.

Under the recently adopted RENURE framework (Directive (EU) 2026/288), mineral concentrates from reverse osmosis are formally recognised as RENURE fertilisers, which allows application above the standard 170 kg N/ha/yr manure limit, up to an additional 80 kg N/ha/yr, if the quality criteria are met. One practical condition from the RENURE directive is that mineral concentrates with a pH higher than 5.5 have to be applied by injection, or equivalent measures, to prevent ammonia emissions[51].

The mineral concentrate can be mixed with livestock manure directly before application and spread on agricultural land in a single operation, which simplifies logistics for farmers. Experience from the Dutch pilot programme, and confirmed by an interview with case study #4, shows that the produced mineral concentrate is accepted by farmers in the Netherlands, with all produced volumes applied on land[36]. The product is particularly suitable for application on soils saturated in phosphorus where conventional manure cannot be applied due to phosphorus limits, but where a nitrogen (and potassium) demand remains. Currently, farmers would have to buy additional synthetic fertilisers to fill up this nitrogen demand. The mineral concentrate has been demonstrated to reduce this dependence on synthetic nitrogen fertilisers[36,49].

The main limiting factor for market uptake is the high volume relative to nutrient content, see Table 15. This means that transport costs are significant and the product would be most economically viable when applied locally within a short distance of the production site. This geographic constraint connects the market demand to the regions of production, which are the intensive livestock areas with the highest surplus manure volumes.

Market potential for mineral concentrates

Market demand is expected to grow strongly as EU countries implement RENURE framework[36]. Additionally, the market demand is expected to grow further as manure derogations are phased out. Farmers who could previously apply 230-250 kg N/ha can now only apply 170 kg N/ha, leaving them with surplus manure that cannot be spread. Processing this surplus into RENURE fertilisers allows part of the nitrogen to be applied above the 170 kg N/ha manure limit (up to an additional 80 kg N/ha), making these products an attractive alternative to untreated manure. This means RENURE not only solves the disposal problem but actively allows more nitrogen to be applied per hectare than would be permitted with untreated manure.

According to NCM (2025), the Netherlands has a total RENURE potential of 55 kt N. Around 60% of this potential is expected to come from RO, corresponding to 33 kt N or 4.1 Mt of mineral concentrate based on a typical nitrogen content of 8 kg N/t (Table 15). While ammonium sulphate and nitrate producers hold 1.5 Mt, giving a total RENURE eligible capacity of 3.8 Mt[34]. The mineral concentrate share is therefore approximately 60% (2.3/3.8) of the total RENURE capacity. The market acceptance in the Netherlands is taken as an indication of the achievable uptake once mineral concentrate is recognised as RENURE across the EU. It reflects a market that has developed under a national derogation over more than a decade, and uptake in Member States without that type of stimulation in the past may develop more slowly.

Assuming an estimated market potential of 90% of the feedstock-based potential of 24 Mt, **the estimated market is approximately 22 Mt of RO mineral concentrate in the EU27**.

An important limitation for the mineral concentrates produced without RO, cases 19 and #20, is that these products are not automatically covered by RENURE and therefore face lower market potential due to standard manure application limits.

[50] Nutriman (2021) Het gebruik van mineralenconcentraat als meststof. https://nutriman.net/sites/default/files/2021-05/Thematic_training_material_MINERAL_CONCENTRATE_NL.pdf
[51] European Commission (2026) C (2026) 662 final. https://environment.ec.europa.eu/publications/commission-directive-amending-nitrates-directive-regards-use-certain-fertilising-materials-livestock_en

4.5 Scale-up potential

Table 19 summarises the scale-up potential for mineral concentrate produced via reverse osmosis in the EU27. The feedstock-based potential is estimated at 24.5 Mt, derived from the pig manure surplus in intensive livestock regions, estimated at 61 Mt across the EU27 and applying the conversion yield of 40% which was observed at case study #4. The market potential of 22 Mt is estimated at 90% of the feedstock-based potential, reflecting the strong and growing demand expected to follow the EU-wide adoption of the RENURE framework, the phasing out of national manure application derogations, and the demonstrated market acceptance in the Netherlands where all produced mineral concentrate is currently applied on agricultural land. Since the market potential (22 Mt) is below the feedstock-based potential (24.5 Mt), it is still estimated that the market is the binding constraint for this technology, mostly due to the large volume of pig manure available.

Table 19: Estimation of the scale-up potential of mineral concentrate from reverse osmosis in the EU27. Source: estimation BTG based on several sources as mentioned in the text.

	Mineral concentrate produced via reverse osmosis (Mt)
A. Feedstock-based potential	**24**
- Pig manure	24
B. Market potential	**22**
C. Total potential (minimum of A & B)	**22**
D. Current production	**0.8**
E. Potential to scale up (C - D)	**21**
Scale-up factor	26

At current production of the estimated 0.8 Mt/yr, concentrated mostly in the Netherlands, the scale-up potential is up to 21.2 Mt, with a scale-up factor of 26. This large scale-up factor reflects the relatively early stage of development of the technology throughout the EU, with the Netherlands as exemption, where the regulatory framework enabling the mineral concentrate to be used above the standard manure application limit has only recently been established at the EU level through the RENURE framework. To realise this indicative potential of mineral concentrate from manure via reverse osmosis, the implementation of the RENURE framework will have to be implemented into national legislation across the member states, an investment in the RO technology in intensive pig farming regions and the solving of barriers discussed in section 4.6.

4.6 Barriers to scale up

Regulatory status

Despite the adoption of the RENURE framework, mineral concentrate produced via reverse osmosis remains legally classified as a manure-derived product rather than a synthetic fertiliser substitute, in most regulatory contexts. Under the RENURE framework, the RENURE fertilising products may be applied up to an additional 80 kg N/ha above the standard 170 kg N/ha manure limit, which is a significant reduction compared to the additional 160 kg N/ha that was permitted under the Dutch national pilot programme. This step down in the permitted additional application rate relative to the pilot may reduce the financial incentive for producers and farmers who were going to invest or had invested based on the pilot conditions.

For free trade as fertilising product within the EU, the mineral concentrate product must additionally comply with the EU Fertilising Product Regulation (EC/2019/1009). Furthermore, further quality improvements of mineral concentrates are necessary to meet the RENURE quality requirements, including the mineral N/total N ratio of ≥90%, which not all current installations achieve[34,49].

Case study #20 illustrates an additional regulatory barrier, namely that mineral concentrate produced via ultrafiltration without a RO step, does not qualify as a RENURE fertilising product, as the regulation

explicitly requires RO as the production technology[52]. The standard animal manure application limits therefore are applicable to this product, which significantly restricts its market potential compared to RO-based mineral concentrate.

Competition with direct manure application

The mineral concentrate that does not fall under RENURE has limited standalone financial value and must compete with direct manure application. In nutrient-surplus regions where farmers are legally obliged to dispose of their manure, mineral concentrate production could offer a solution. However, in regions without manure surplus, there is no economic incentive yet to invest in RO treatment when direct land application is possible. The product's financial value is thus closely tied to the regulatory status and the regulatory pressure on manure disposal.

High transport costs and storage

The relatively low nutrient concentrations in mineral concentrate mean that large volumes must be transported. According to case study #4, transport costs over distances greater than about 50-100 km neglect the economic viability of the product. This geographic constraint ties the product closely to the intensive livestock regions.

In the Netherlands, mineral concentrate may only be applied to agricultural land between February and September. Pig manure is produced continuously throughout the year, so production and processing continue during the period that the mineral concentrate cannot be applied to agricultural land. Approximately five months of production must therefore be stored, which requires storage capacity at the processing site or at the receiving farm. Comparable periods will apply in other Member States, though the exact dates may differ. Case study #4 solves this storage issue by processing the mineral concentrate in these winter months further by evaporation into a potassium fertiliser, as discussed in section 0.

4.7 Conclusions and recommendations

In contrast to the widely applied anaerobic digestion of various waste streams, the further treatment of digestate into mineral concentrates via reverse osmosis or ultrafiltration or evaporation is not as widely spread. In the Netherlands, due to the pilot mineral concentrate, related to the upcoming RENURE legislation, several companies have built installations to treat either raw pig manure or, in a lesser extent, the digestate of pig manure by reverse osmosis.

It is estimated that currently about 0.8 Mt/yr of mineral concentrate from reverse osmosis is produced. Starting with a total volume of 61 Mt pig manure available within the EU and considering the ongoing RENURE legislation implementation on the usage of mineral concentrates from reverse osmosis, a scale-up potential of 21 Mt of mineral concentrate was estimated.

The main barrier for further upscaling for mineral concentrates that are not produced via reverse osmosis, e.g. via evaporation and/or ultrafiltration, is the definition of RENURE criteria, which forces treatment by reverse osmosis. It is uncertain if the other technologies will be allowed in the future as RENURE fertilising products. The relatively low nutrient concentrations in the mineral concentrate result in a large transportation volume, which reduces the economic viability of transporting the product to other regions.

[52] RVO (n.a.) Onderzoek naar mineralenconcentraat. https://www.rvo.nl/onderwerpen/mest/mineralenconcentraat

5 Digestate treatment to potassium fertiliser

5.1 Introduction

Case study #4 separates the digestate into a liquid and solid fraction. The liquid fraction is treated by reverse osmosis into a mineral concentrate, as discussed in section 3. In winter times, when the mineral concentrate cannot be applied to agricultural land, the mineral concentrate can be evaporated into a solid potassium fertiliser and an ammonia solution. The ammonia solution is used in another process for flue gas purification. The potassium fertiliser containing 7% K_2O (ca. 35% dry matter; 0.4% P; 1% N) is mixed with animal manure and applied to agricultural land, for example to potato fields which require potassium.

With a dry matter of 35%, the product is not as concentrated as conventional solid potassium fertilisers with dry matter contents of about 50-60%[53].

5.2 Current production and maturity

Current production

It seems like the specific process of case study #4 of producing a solid potassium fertiliser via reverse osmosis of the liquid fraction of pig manure or pig manure digestate, followed by evaporation, is essentially unique in documented European literature. While potassium-rich liquid fractions from manure processing are recognised in literature as product from membrane-based nutrient recovery, further concentration of this into a solid potassium product is according to our knowledge not documented on commercial scale beyond case study #4.

Therefore, the **current production of this potassium fertiliser from mineral concentrate evaporation is the 15 kt** that case study #4 produces yearly, by evaporating 50 kt of mineral concentrate.

Maturity

Although this specific process is not applied widely, the evaporation technology is mature and is applied commercially on other liquid streams such as manure or the liquid fraction of digestate. The process configuration of case study #4 is commercially operational.

5.3 Feedstock-based production potential

In theory, if all calculated feedstock-based potential of the mineral concentrate (24.5 Mt, as estimated in section 4.3) would be evaporated, 7.3 Mt of potassium fertiliser can be produced. However, as the mineral concentrate is RENURE eligible and the market demand is expected to grow, it seems unlikely that all this mineral concentrate is available for evaporation. Following the process of case study #4, namely that in summer, the mineral concentrate is applied, whilst in winter, the mineral concentrate is processed into the potassium fertiliser. This is mostly due to the large storage that would be required to store the mineral concentrate during winter, as mineral concentrate can only be applied during the growing season. The potassium fertiliser also cannot be applied in winter but requires less storage space and has lower transport costs per kg of potassium. About 50% of the total mineral concentrate production is therefore evaporated and processed into a potassium fertiliser.

Following this reasoning, 12.2 Mt mineral concentrate would be available for evaporation, resulting in **3.7 Mt feedstock-based potassium fertiliser**, using a conversion of 30% from case study #4.

[53] Mitchell (2017) Nutrient Content of Fertilizer Materials. https://www.aces.edu/wp-content/uploads/2018/11/ANR-0174_NutrientContentFertilizerMaterials_103119L-1.pdf

5.4 Applications and potential market size

The market for solid potassium fertiliser from mineral concentrate evaporation is currently limited and represents a barrier for scale-up. Case study #4 produces approximately 15 kt/yr as a seasonal product when mineral concentrate cannot be applied to land during winter months, and they report limitations in selling the product due to high chloride concentrations because of the pig manure. The product is transported 300-400 km to potato-growing regions in Germany and in the Netherlands, where it is mixed with animal manure to achieve a more balanced NPK profile.

This potassium fertiliser could mostly be usable on phosphorus saturated soils where it could be applied without exceeding the phosphorus requirements or even regulatory allowance like in the Netherlands.

An indicative market demand estimate for the solid potassium fertiliser can be derived from the supplementary potassium requirements of potato cultivation in the Netherlands and Germany, the primary target markets based on case study #4 current distribution. Potatoes have a relatively high potassium demand, resulting in average potassium required application rates of 200-400 kg K_2O/ha[54]. A portion of this will be supplied by animal manure that is already applied.

Assuming that this fertiliser is relevant for soils that have to follow a phosphorus limit, like the Dutch phosphorus application standard on medium to high P arable soils, which allows for a maximum of 40-70 kg P_2O_5/ha[55]. With an average manure content of 1.7 kg P_2O_5/t fresh matter[56], the P application standard restricts the manure application to approximately 24-41 t/ha on these soils, delivering approximately 52-91 kg K/ha at typical potassium content of 2.2 kg K_2O/t fresh matter[56]. The additional potassium requirement is derived using the Dutch phosphorus application standard as proxy for the phosphorus limits applying on phosphorus-saturated soils. Comparable limits apply in other Member States under the Nitrates Directive, but the permitted rates differ, and the resulting estimate should therefore be read as indicative for the EU27 rather than as a Member State specific calculation.

With the potato potassium requirement of approximately 200-400 kg K_2O/ha, the additional potassium requirement that cannot be supplied by animal manure is therefore about 148-309 kg K_2O/ha. At a K_2O content of 7%, this corresponds to an application of approximately 2.1-4.4 t/ha.

The top 5 potato producing countries in 2025 in the EU are Germany, France, Poland, the Netherlands and Belgium, together having 1.03 million ha of potatoes, making up 69% of all EU potato farms[57]. This would result in an **indicative market estimation of 2.1-4.5 Mt potassium fertiliser**, on average 3.4 Mt, supplying 0.15-0.32 Mt K_2O.

A market driver could be a potential application under the Fertilising Product Regulation (FPR) with a CE-mark.

5.5 Scale-up potential

The scale-up potential is based on the amount of mineral concentrate that could be seasonally evaporated into a solid potassium fertiliser and the estimated market demand for potatoes. The feedstock-based potential is estimated at 3.7 Mt potassium fertiliser, assuming that 50% of the calculated mineral concentrate potential is evaporated, following the seasonal logic of case study #4. The market potential is estimated at 3.4 Mt, based on supplementary potassium demand in potato growing regions. The resulting potential is therefore slightly estimated to be market-limited rather than feedstock-limited. Compared to the current product ion of 15 kt/yr, this indicates a high theoretical scale-up potential.

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[54] Ravensbergen et al. (2023) Current Phosphorus and Potassium Fertiliser Application Rates Do Not Limit Tuber Yield and Quality in Potato Production Systems in the Netherlands. *Potato Research*, vol. 66, pp. 1033-1058. https://doi.org/10.1007/s11540-022-09613-5

[55] RVO (2026) Fosfaatdifferentiatie. https://www.rvo.nl/onderwerpen/mest/gebruiken-en-uitrijden/gebruiksnormen-gebruiksruimte/fosfaatdifferentiatie

[56] ADHB (2023) Nutrient Management Guide (RB209). https://projectblue.blob.core.windows.net/media/Default/Imported%20Publication%20Thumbs/RB209/2023/NutManGuideRB209S2_230526_WEB.pdf

[57] Eurostat (2026) Crop production in EU standard humidity. https://doi.org/10.2908/APRO_CPSH1

Table 20: Estimation of the scale-up potential of potassium fertilisers from evaporation in the EU27. Source: estimation BTG based on several sources as mentioned in the text.

	Potassium fertiliser (8% K) (Mt)
A. Feedstock-based potential	**3.7**
- 50% of total mineral concentrate (section 4)	3.7
B. Market potential	**3.4**
- Potato farms	3.4
C. Total potential (minimum of A & B)	**3.4**
D. Current production	**0.015**
E. Potential to scale up (C - D)	**3.3**
Scale-up factor	223

5.6 Barriers to scale up

Several factors constrain the market demand for this product. The high chloride concentration, which is inherent to pig manure-derived products, limits the applicability to chloride tolerant crops. The relatively low potassium concentration (7% K at 35% DM) means transport costs are significant relative to product value, which limits the economically viable market demand. Furthermore, the product currently has no regulatory classification as EU fertilising product and in its current shape the potassium fertiliser cannot be sold under the RENURE framework. This complicates the marketing and farmer acceptance. Since this product is made from animal manure, it still has the label of manure product, which prevents mixing with other bio-based fertilisers, RENURE fertilising products or conventional fertilisers.

Case study #4 evaporates mineral concentrate into a solid potassium fertiliser during the months when the liquid product cannot be applied (as described in section 4.6), avoiding the need for storage by making a transportable product. The solid product itself is stored until the potato growing season.

5.7 Conclusions and recommendations

Digestate treatment to potassium fertiliser represents a specific seasonal valorisation route for mineral concentrate when direct land application is not possible. The process configuration of case study #4 is commercially operational, but the current production is limited, and the route appears to be unique in documented European practice. The calculated scale-up potential is substantial, with a total estimated potential of 3.4 Mt compared to current production of 0.015 Mt. However, the product is considered a niche potassium fertiliser rather than a general substitute for conventional potassium fertilisers. The high chloride content and manure-based regulatory status constrain its wider market uptake. The most relevant application appears to be in potassium requiring, chloride-tolerant crops such as potatoes. To support scale-up, further work should focus on improving regulatory clarity and identifying regional markets where transport distances, crop demand and nutrient limits make the product agronomically and economically viable.

6 Struvite precipitation

6.1 Introduction

Phosphorus can be recovered from municipal and industrial wastewater streams. Theoretically, phosphorus recovery is possible from the liquid phase, sludge, and sludge ashes. 90 – 95% of the incoming phosphorus is incorporated into the sludge, and phosphorus recovery from the liquid phase at the current stage of development will not exceed 20% to 40% while P-recovery technologies from the sewage sludge and sludge ash have a higher potential for P-recovery (Shaddel et al., 2019). Figure 6 shows the prominent and already applied concepts for P-recovery and recycling from sewage sludge.

Struvite precipitation from sludge liquor or side stream has been proven viable for various WWTP operations. Mostly, it is an enhanced biological phosphorus removal (EBPR) process combined with anaerobic digestion followed by struvite precipitation on sludge liquor. The main benefits are improved sludge treatment and dewaterability of the sludge and thus lowered costs of sewage sludge removal. In addition, operational challenges such as blockage frequency of valves and pipes are avoided, improving the reliability of the operation. Moreover, additional income can be generated by the sales of struvite as fertiliser or raw material for fertiliser production.

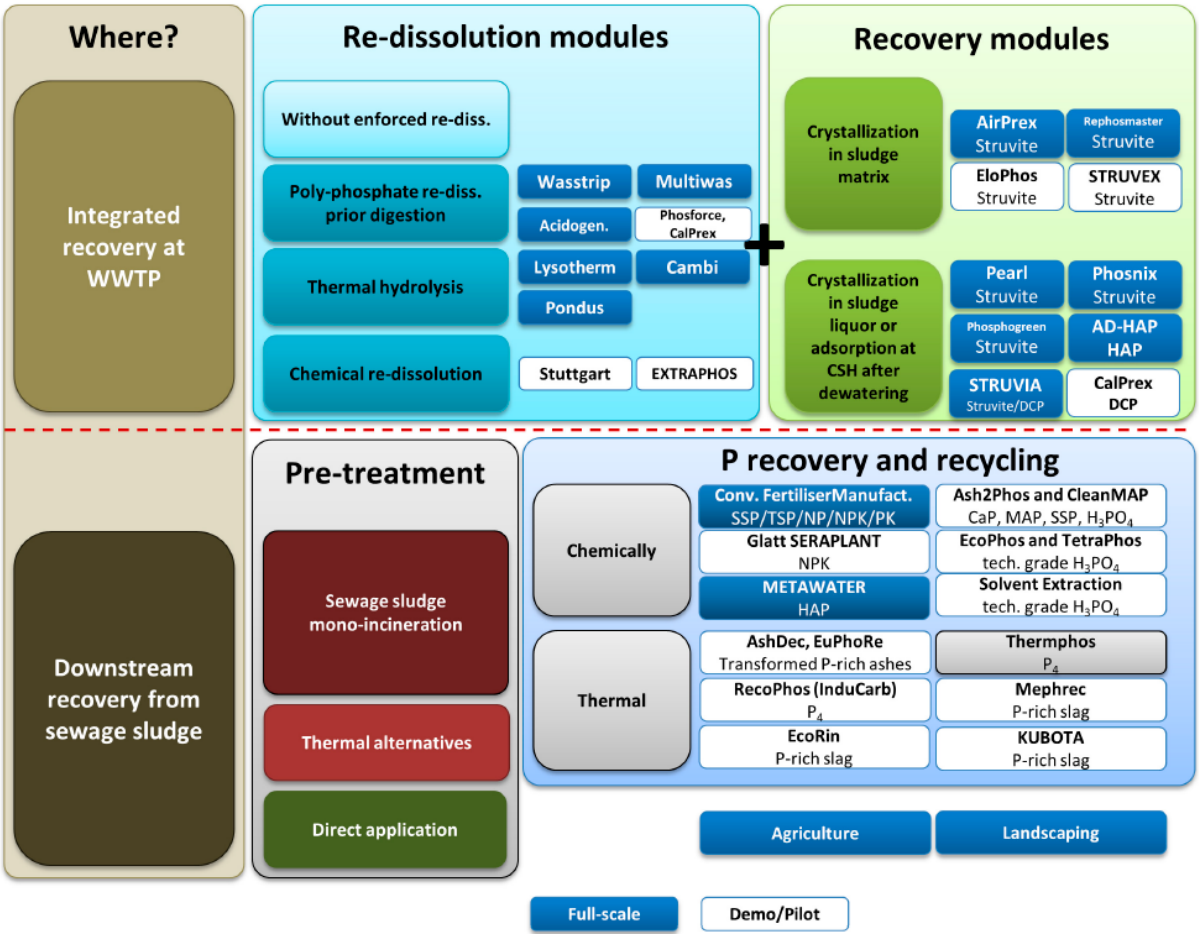


Figure 6: Prominent and already applied concepts for P-recovery and recycling from sewage sludge. Source: Shaddel et al (2019)[59]

Case study #17 and #18 are focused on struvite production from mainly municipal wastewater and industrial waste streams from potato processing and dairy industry. By an additional pretreatment step, indicated in Figure 6 as "re-dissolution modules" (e.g. Wasstrip combined with Pearl) the rate of P recovery can be improved. Other technologies are still either in research (laboratory) or development (pilot) phase, improving maturity, lowering costs, and gathering data for full-scale design.

6.2 Current production and maturity

Current production

Based on the dentification of 39 operational European struvite production plants, Muys et al (2021)[58] have estimated that in 2020 **10.9** (9.7 – 12.1) **kt of struvite** was produced, of which **7.4** (6.2 – 8.5) kt from municipal WWTPs, and **2.9** (2.4 – 3.3) kt from the potato industry. With a total share of 69 – 74% of EU27 production, the Netherlands (35-43%), Germany (15%) and Belgium (16-20%) are the largest struvite producers in the EU27 (Muys et al., 2021)[58]. The share of current production compared to the total feedstock-based production potential is provided in Table 21. Given the current share of production in available feedstock-based potential, it shows that from the feedstock-side there is a lot of opportunity to scale up production, especially by applying the technology at more municipal WWTPs, i.e. upscaling in numbers.

Table 21: Share of current production of feedstock-based production potential in the EU27. Source: own assessment mainly based on JRC (2019)[65] and Muys et al (2021)[58] in kt struvite

Source of struvite	Feedstock-based potential	Current production	Share current production in feedstock-based potential
Municipal wastewater	285	7.4	2.6%
Wastewater potato industry	8.3	2.9	35%
Wastewater dairy industry	16.8	0.7	4%
Total	**310**	**10.9**	**4%**

Technical maturity

JRC (2019)[65] lists 37 struvite recovery plants implemented between 2006 and 2019. Muys et al (2021)[58] identified 39 operational European struvite installations and Shaddel et al (2019)[59] identified 80 struvite production plants worldwide of which more than 60 plants are municipal wastewater treatment plants. According to Vasa et al (2021)[60] as of 2020, there are 100 full scale struvite recovery plants in operation in the world. These full-scale plants are operational mainly in a few countries in Europe (the Netherlands, Belgium, Germany, Austria), North America, and Asia (Japan).

Shaddel (2019)[59] identified 19 struvite production technology providers, of which 8 have installed more than one system. Important players are PEARL (Ostara), Airprex, PhosPAQ, Anphos, PHOSNIX, NuReSys, Phoshogreen and Multiform. For example, PEARL (Ostara) has installed 22 plants, of which 17 in the USA and 3 in the EU (NL, IE, ES), and 2 in other European countries (UK, NO)[61]. NuReSys shows on their website 9 municipal example projects, and 5 projects on industrial phosphate recovery, mainly in the potato industry and one dairy plant.

Given the number of implemented plants and that buyers can choose from a range of >5 suppliers, it can be concluded that the technology is mature and reached TRL 9, already for at least a decade.

The size of the installation varies depending on the size of the wastewater treatment system. The NuReSys website shows a range of capacities of their reference plants from 5 – 140 m3/hour for municipal systems and 120 – 340 m3/hour for industrial systems, as shown in Table 22 and Table 23.

[58] Muys, M., et al. (2021) A systematic comparison of commercially produced struvite: Quantities, qualities and soil-maize phosphorus availability. Science of the Total Environment, 756, 143726. https://doi.org/10.1016/j.scitotenv.2020.143726
[59] Shaddel, S., Bakhtiary-Davijany, H., Kabbe, C., Dadgar, F., & Østerhus, S. W. (2019). Sustainable Sewage Sludge Management: From Current Practices to Emerging Nutrient Recovery Technologies. Sustainability, 11(12), 3435. https://doi.org/10.3390/su11123435
[60] Tejas N. Vasa, Sabumon Pothanamkandathil Chacko (2021) Recovery of struvite from wastewaters as an eco-friendly fertilizer: Review of the art and perspective for a sustainable agriculture practice in India, Sustainable Energy Technologies and Assessments, Volume 48, 101573, ISSN 2213-1388, https://doi.org/10.1016/j.seta.2021.101573.
[61] See https://www.ostara.com/nutrient-recovery/municipalities-industries-more/

Table 22: Design flow and phosphorus influent of a number of municipal NuReSys installations in Europe and North America[62].

Plant	Country	Design flow (m^3/hour)	PO-P influent (mg P/l)
Grand Rapids, MI, Water Reclamation Facility	USA	20	150
Tres Rios Water Reclamation Facility	USA	55	250
Centrate Struvite System in Lodz	PL	80-100	300-350
Hybrid NuReSys System	NL	140	450
Centrate P-recovery technology	NL	5	650
Digested Sludge Processing	BE	8	100
P-recovery system in Warsaw	PL	40	390
Centrate installation in Lower Saxony	DE	20	100

Table 23: Design flow and phosphorus influent of a number of industrial NuReSys installations in Europe and North America [63].

Plant	Country	Design flow (m^3/hour)	PO-P influent (mg P/l)
Large US food processing company for their Dutch facility (to remove bulk of Phosphorus and reduce nutrient flow towards post aerobic treatment, avoid FeCl3 after anaerobic treatment since they were required to do so, as per discharge requirements).	NL	340	70-80
Biggest Potato manufacturing plant in Netherlands(The phosphate was formerly reduced by addition of FeCl3, PO reduction from 120 – 20 ppm).	NL	120	150
Dairy processing plant in Germany	DE	125	60-65
Another project with the same Potato manufacturing at another site in NL	NL	120	130-175

The installations listed in Table 22 and Table 23 are located in Europe and North America, and are reported to illustrate the range of installed capacities. The production and market estimates in this section refer to the EU27.

6.3 Feedstock-based production potential

Struvite can be recovered from municipal and industrial wastewater streams, especially from the potato and dairy industry (JRC 2019). Below an indicative estimation is made of the struvite production potential, based on available phosphorus in the waste streams and basic technical considerations.

Municipal wastewater treatment

The technologies precipitate phosphorus from wastewater that otherwise would become part of sewage sludge. Based on Eurostat data (env_ww_spd)[64] it was estimated that within the EU yearly 6 Mt dry matter of sewage sludge from urban wastewater treatment plants is produced. According to JRC (2019)[65] for the year 2030, the total incoming amount of phosphorus in municipal WWTPs is estimated at 360 kt of P. For a population of 522 million this corresponds to a daily discharge of 1.9 g P per person per day, which is in

[62] NuReSys (n.a.) Municipal project. https://nuresys.com/municipal-project/
[63] NuReSys (n.a.) Industrial project. https://nuresys.com/industrial-project/
[64] See van der Voort and Vis (2025) Technical availability of feedstock supply, FertiCovery D5.1.
[65] JRC (2019) Technical proposals for selected new fertilising materials under the Fertilising Products Regulation. Also known as "the Strubias report". https://dx.doi.org/10.2760/186684

line with other literature, that show a discharge between 1.8 and 2.2 g/day[66]. According to Eurostat[67], the EU27 (excluding UK) has a population of 452.7 million in 2030, which result in a total discharge of 312 kt of P in municipal WWTPs within the EU27. Part of the WWTPs will not be suitable for struvite recovery. JRC (2019) estimates that in 2030 69% of the wastewater in the EU will be processed with stringent treatment, of which 40% will use enhanced biological phosphorus removal (EBPR) and struvite production, leading to 86.1 kt of P that could be treated with struvite precipitation. State-of-the-art first-generation struvite precipitation technologies such as Ostara Pearl have a recovery potential of 10-25% of the incoming wastewater stream (Amann et al 2018)[68]. We assume a recovery potential of 20%. JRC (2019) indicates that second generation P-precipitation technologies, using re-dissolution modules (e.g. by combining Wasstip with Ostera Pearl), an efficiency of 50% can be reached. JRC furthermore assumes that in 2030 60% of this wastewater could be treated with first generation P-precipitation and 40% with second generation technology, resulting in 10.3 plus 21.5 kt, thus **31.9 kt of P**. Assuming a P content in Stuvite of 11.2% this results in a yearly production potential of **285 kt of struvite** from municipal wastewater in the EU27.[69].

Struvite production from industrial wastewater

JRC (2019) identified the potato processing and dairy industry as the two main industries with a high potential for struvite production. Effluent waters from **potato processing** facilities contain large amounts of phosphate. During preparation of the prebaked frozen product, potatoes are treated with sodium acid pyrophosphate after the blanching treatment, preventing that iron in the potato reacts with chlorogenic acid, avoiding after-cooking grey discoloration (JRC 2022)[70]. Based on the processing of 8.3 Mt potatoes and a struvite recovery rate 1 tonnes struvite per 500 tonnes potatoes JRC (2019) estimates a total maximal recovery potential of about 16.6 kt of struvite per year[71]. This number may be on the conservative side as the European Potato Processors' association indicates a European production of 7.5 Mt of French fries and potato derived products[72], which require in the order of 12.8 Mt potatoes assuming a factor 1.7 tonnes potatoes per tonne French fries[73], which would result in a total recovery of 25.5 tonnes struvite (54% more than the estimation of JRC). Taking the more conservative 16.6 kt struvite of JRC (2019), and assuming that 50% (25 - 75%) could be recovered as these wastewater treatment systems already rely on Mg or Cg salts for precipitation, this results in a yearly potential of **0.9** (0.5 – 1.4) **kt P**, and **8.3 (**4 – 12) **kt of struvite**.

Secondly, the **dairy industry** produces P-rich waters, and the BAT conclusions for the food, drink and milk industries, indicate that phosphorus recovery from P-rich waters (> 50 mg L-1), in order to reduce emissions to water, is a suitable technique. According to JRC (2022) the P-rich concentrates formed are often referred to as struvite, though they may not classify as CMC 'precipitated phosphate salts' due to their high organic C content. JRC (2019) calculated that about 2-3% of incoming milk is lost during cleaning operation, via washing steps and through occasional milk spills. Typically, milk contains 1 kg P per tonne (JRC 2019). In 2024, 150.8 million tonnes of milk was processed by the dairy sector (Eurostat 2025)[74], resulting in a P flow of 3.8 (3 – 4.5) kt P. Assuming that 25-75% of all wastewater treatment plants from the dairy industry rely on Ca and Mg salts, the total P realistic recovery potential is **1.9** (0.8 - 3.4) **kt P**, which is the equivalent of **16.8** (6.7 – 30.3) **kt struvite per year**.

Total feedstock-based production potential

[66] See https://www.sciencedirect.com/science/article/abs/pii/0043135476900932, https://lanfaxlabs.net/Technical-Guide-phosphorus%20calculations%20in%20wastewater-16DEC16.pdf and https://www.hydro-int.com/sites/default/files/landing-pages/hydro_international_white_paper_-_phosphorus_-_what_is_it_and_why_do_i_need_to_remove_it_from_wastewater.pdf
[67] https://doi.org/10.2908/PROJ_23NP
[68] A. Amann, O. Zoboli, J. Krampe, H. Rechberger, M. Zessner, L. Egle, Environmental impacts of phosphorus recovery from municipal wastewater, Resources, Conservation and Recycling, Volume 130, 2018, Pages 127-139, ISSN 0921-3449, https://doi.org/10.1016/j.resconrec.2017.11.002 .
[69] Assuming a phosphorus content of 11.2% in Struvite as applied by Muys et al (2021). Chemically pure struvite ($NH_4MgPO_4 \cdot 6H_2O$) has a P content of 12.6%.
[70] JRC (2022) Technical proposals for by-products and high purity materials as component materials for EU Fertilising Products https://publications.jrc.ec.europa.eu/repository/handle/JRC128459
[71] JRC indicates a potato production of 8.3 Mt/yr (BE and NL). This is roughly in line with a potatie According
[72] https://euppa.eu/_library/_files/EUPPA_facts_and_figures_2025_updated.pdf
[73] https://www.potatochipprocessing.com/how-many-potatoes-to-get-1kg-of-fries%EF%BC%9F/
[74] Eurostat (2025) Milk and milk product statistics

Based on the average values of the potentials found, in Table 24 the total feedstock-based production potential is provided.

Table 24: Total feedstock-based struvite production potential in the EU27.
Source: own assessment mainly based on JRC (2019)[65] and Muys et al (2021)[58]

Source of struvite	Struvite (kt)	P (kt)	% of total
Municipal wastewater	285	32	92%
Wastewater potato industry	8.3	0.9	3%
Wastewater dairy industry	16.8	1.9	5%
Total	**310**	**35**	100%

6.4 Applications and potential market size

Struvite can be used directly as fertiliser or serve as raw material for the production of a (partly) bio-based fertiliser. The physical properties of struvite are of relevance to enable its agronomic use.

Direct application

Struvite as produced by Ostara – Pearl is shaped as round grains ("pearls") and can be applied directly with a conventional fertiliser spreader. Struvite from municipal wastewater can be used on sports fields during construction and major maintenance, as well as in the construction and renovation of golf courses. The phosphorus is released slowly which makes struvite potentially applicable as a first fertiliser (starter fertiliser) with a low nitrogen requirement in the following crops: peas; iceberg lettuce; hyacinths, crocuses, dahlias, and gladioli; various perennials with a low nitrogen requirement at the start; and heather species and cuttings of roses and some fruit varieties STOWA (2016)[75]. As summarised in Table 25, STOWA (2016) estimated the maximum amount of directly applicable struvite in the Netherlands at 7.3 (6.4 – 8.3) kt per year. This is higher than the Dutch struvite production in 2020 of 4.3 kt/yr, but below the production potential of municipal WWTPs in the Netherlands, which is estimated at 41.1 kt struvite per year.

Table 25: Estimated maximal market for direct struvite application in the Netherlands.

Market estimation (based on 2015 areas)	Struvite (kt)
Arable farming (peas)	1.1
vegetable farming (iceberg lettuce)	3.1
Floriculture (hyacinths, crocuses, dahlias, and gladioli)	1.4
Sport fields	1.7
Golf courts	0.2
Total	**7.3**
Estimated NL struvite production in 2020 (all)	4.3
Feedstock-based production potential NL (only municipal WWTPs)	41.1

Source: Market estimation: STOWA (2016)[75], in case of ranges, the average value is taken. Estimated NL struvite production taken from Muys et al (2021). Production potential based on Dutch population (18.4 million), 1.9 g P/day, 37% recovery efficiency.

STOWA (2016) shows that the agronomical applicability of the P in struvite in the above-mentioned markets is similar or even better than conventional fertilisers. However, in many cases the application of P needs to be followed up by application of N-fertilisers, which results in additional costs to farmers compared to application of NPK-fertilisers that can be provided in one go.

[75] STOWA (2016) Marktverkenning en gewasonderzoek struviet en struviethoudende producten uit communaal afvalwater.

Struvite as component in N-P-K fertilisers

There is a market for component fertilisers that are containing N-P-K in suitable ratios. If struvite is to be used in N-P-K fertilisers, the P contained in struvite must either be incorporated into a complex granule or blended with N and K granules (Muys et al 2021). An example is "Gronamic Golf 6-2-4", a mini-granule fertiliser for use on golf greens, tees, stadium pitches, tennis courts and lawns, that consist of struvite (P), polyhalite (K, Mg), and conventional mineral nitrogen (N)[76].

Although considerable amount of research is conducted to agricultural application of struvite, our literature search did not result in concrete examples of current direct application of struvite on agricultural land. Therefore, conservatively, we estimate the struvite market potential for direct application or mixed in N-P-K, based on the market in golf greens, and other non-agricultural grass applications, which seems to be most established. Taking the STOWA (2016) market estimation of 0.2 kt struvite in golf courts and 1.7 kt in sport fields in the Netherlands (see Table 25), and extrapolation of these numbers to the EU27 based on population[77], the EU27 market for would have a volume in the order of **47 kt struvite**. The potential market for direct application or N-P-K blends may be much higher if farming and application on agricultural grass land would be considered as well.

Struvite as raw material in conventional P-fertiliser production

Struvite can also serve as raw material for the production of traditional P-fertilisers with a well-known chemical composition such as DAP, MAP, SSP, and TSP etc[78] (JRC 2019). According to JRC (2019) the EU28 production of these fertilisers are in the order of 200 kt P in DAP, 18 kt P in MAP, 88 kt P in SSP, and 53 kt in TSP, totalling up to 359 kt P. Quantitative data on current struvite uptake by traditional fertiliser industry was not found. However, interest from industry can be indicated indirectly. For example, in an (approved) request for end-of-waste status of struvite from Amsterdam-West[79], it is indicated that maximally 10% struvite together with regular raw materials will be used for fertiliser production. Extrapolating this blending rate of 10% with European traditional P-fertiliser production of 359 kt P, leads to an indicative struvite market potential as blend in traditional P fertiliser of 36 kt P, which corresponds to an annual target market of **321 kt struvite**.

Struvite in organic farming

In 2023 The EU Organic Farming Regulations have been modified to authorise "Recovered struvite and precipitated phosphate salts", as defined in the EU Fertilising Products Regulation (FPR)[80], making it currently the only sewage sludge-derived product permitted for use in organic farming across the EU.

Raw phosphate rock, Tetracalcium phosphate and aluminium calcium phosphate (CaAl(PO4)2) are synthetic mineral fertiliser P sources allowed in organic farming. Magaya et al (2024) estimates that that organic crop farming in the EU+UK removes 61.3 kt of P per year, or 59.7 kt P in the EU (excl. UK). About 30% of this removal is offset by mineral fertilisers (Magaya et al 2024). Thus, in base year 2023 there is potential to replace 17.9 kt of mineral P in current organic farming. The share of the EU's agricultural land under organic farming increased from 5.9% in 2012 to 10.8% in 2023 as a result of an increasing demand for organic products and policy support (EEA 2025)[81].

Extrapolating the annual compound growth rate from 2012 to 2023 of 5.7% per year to 2030 results in a share of organic farming of 15.9%. The European Green Deal strategies set the target that at least 25% of the European Union's agricultural area should be dedicated to organic farming by 2030. Assuming that 15% of the mineral P can be replaced by struvite, we derive at a struvite demand from organic farming of 24 kt in 2023, **35 kt** in 2030 extrapolating past growth rates of organic farming and 55 kt in case the 25% target of organic farming in the EU27 is achieved by 2030. See Table 26.

[76] https://icl-growingsolutions.com/en-ie/turf-landscape/knowledge-hub/the-benefits-of-gronamic-golf-6-2-4-a-hybrid-fertiliser-for-sustainable-turf-management/
[77] Based on an NL population of 18.0 million and an EU population of 452.7 million.
[78] DAP: Diammonium phosphate; MAP: monoammonium phosphate; TSP: tripel superphosphate; SSP: single superphosphate.
[79] See link.
[80] https://www.phosphorusplatform.eu/scope-in-print/news/2306-recovered-struvite-authorised-in-eu-certified-organic-farming
[81] https://www.eea.europa.eu/en/analysis/indicators/agricultural-area-used-for-organic

Despite this market potential, although quantitative data was not found, likely the current level of struvite application in organic farming is still low to absent.

Table 26: Estimation of market potential of struvite in organic farming in the EU27.
Source: own elaboration, see text.

	2023	2030 (extrapolation)	2030 (EU target)	
% organic farming in total farming	10.8%	15.9%	25%	
Mineral P demand	17.9	26.4	41.4	kt P
Assumed replacement mineral P by struvite	15%	15%	15%	
Market potential struvite	2.7	4.0	6.2	kt P
Market potential struvite	24	35	55	kt struvite

6.5 Scale-up potential

Struvite production can be regarded as a mature technology and available in any desired scale. The main scale-up potential is in the further market roll out. Based on the indications on feedstock-based potential, market potential and current production, it is concluded that current production could increase with a factor 27 to reach full potential. This means that there is a long-term potential to recovery an additional 33 kt of phosphorus on top of current recovery of 1.2 kt phosphorus.

Table 27: Estimation of the scale-up potential of struvite production and application in the EU27 in 2030.
Source: estimation BTG based on several sources as mentioned in the text.

	Struvite (kt)	Phosphorus (kt)
A. Feedstock-based potential	**310**	**34.7**
- Municipal wastewater	285	31.9
- Wastewater potato industry	8.3	0.9
- Wastewater dairy industry	16.8	1.9
B. Market potential	**403**	**45**
- Direct application (golf courts, grass, non-agro sector)	47	5.2
- 10% blending with EU conventional P production	321	35.9
- 15% replacement mineral P in organic farming	35	4.0
C. Total potential (minimum of A & B)	**310**	**35**
D. Current production	**10.9**	**1.2**
- Municipal wastewater	7.4	0.8
- Wastewater potato industry	2.9	0.3
- Wastewater dairy industry	0.7	0.1
E. Potential to scale up (C - D)	**299**	**33**
Scale-up factor	27	27

6.6 Barriers to scale up

It is observed that struvite precipitation is applied in a limited number of EU countries. Although for example the EU Urban Wastewater Treatment Directive (UWWTD) requires Member States to significantly increase wastewater treatment levels, there is currently no obligation to recover phosphorus, for example in the form of struvite. Another barrier to scale up of struvite application, for example in organic farming, is related to the perceived possibility of contaminants in the struvite as it is based on wastewater.

Interviews taken by Magaya et al (2025)[82] indicate that WWTP participants did not observe increased struvite demand after its approval for use in organic farming, indicating limited adoption by organic farmers. Survey results (Magaya et al 2025) show that a majority (n = 59, ~75 %) of organic farmers are opposed to using sewage sludge-based products and only a few (n = 7 ~9%) cited regulatory restrictions as a reason for reluctance. More than 50 % of the participants cited the possibility for contamination as a main concern deterring them from considering wastewater based recycled P products. Participants from the organic farming sector do not perceive urgency that necessitates incorporating more recycled P products into organic farming. An organic farming policy participant suggested that the inclusion of struvite in organic farming guidelines was largely driven by its availability from wastewater treatment plant rather than the demand for new P sources in organic farming. Possible, the introduction of quality standards enforced by labelling and certification could contribute to the farmers' confidence in struvite.

6.7 Conclusions and recommendations

Struvite precipitation from sludge liquor or side stream has been proven viable for various WWTP operations. Mostly, it is an enhanced biological phosphorus removal (EBPR) process combined with anaerobic digestion followed by struvite precipitation on sludge liquor. Struvite precipitation is a mature technology with at least 37 operational struvite recovery plants implemented in Europe, mainly in the Netherlands, Belgium, Germany, and Austria. Municipal WWTPs are the main source of struvite, followed by industrial from mainly potato processing facilities and with potential in dairy industry. Direct application of struvite seems somewhat limited to sport fields and golf courses. A larger market is seen as component in NPK fertiliser and possibly as raw material in conventional P-fertiliser production. Although struvite is currently eligible for organic farming, its uptake is limited, which may be linked to hesitation to use a wastewater / sewage sludge derived product. It is recommended to find ways to reduce this uncertainty, for example by quality certification schemes.

[82] S. Magaya, M. Reimer, G.S. Metson, T-S. Neset, M. Torralba, C.J.E. Schulp, Use of recycled phosphorus products in organic farming in EU member states: Theoretically supported but practically restricted, Food Policy, Volume 134, 2025, 102881, ISSN 0306-9192, https://doi.org/10.1016/j.foodpol.2025.102881 .

7 Stripping and scrubbing towards ammonium sulphate and ammonium nitrate

7.1 Introduction

Ammonia stripping and scrubbing can be applied to recover nitrogen from nitrogen-rich liquid streams such as the liquid fraction of manure or digestate. In this process, the liquid stream is treated with a base (CaO or NaOH) to raise the pH, and the liquid is heated to volatilise dissolved ammonia. The stripped ammonia gas is then led to a scrubber where it is absorbed by an acid solution to produce an ammonium salt. The choice of the acid will determine the product. Adding sulphuric acid (H_2SO_4) will produce ammonium sulphate solution, while the more expensive nitric acid (HNO_3) can also be used to capture ammonia, which produces ammonium nitrate[83]. This pathway is referred to as the end-of-pipe pathway[84] and is applied by case studies #21 and #22.

An alternative configuration to recover ammonia is being used in case studies #4 and #19. These installations use evaporation and condensation rather than acid scrubbing to recover ammonia as ammonia water. Here, the liquid fraction of digestate is concentrated by evaporation, and the resulting ammonia-rich condensate is recovered without an acid scrubbing step. The product, ammonia water with up to 24% NH_3, has a high pH (>10) and is therefore not suitable for direct agricultural application due to NH_3 volatilisation and crop burning[85]. It is therefore used internally or sold for industrial applications, like as a reductant in DeNOx flue gas treatment systems. Since the scope of the project is on the production of bio-based fertilisers, the application of ammonia water will not be further assessed, and this chapter will focus on the scale-up potential of cases #21 and # 22 producing Ammonium nitrate or ammonium sulphate.

Table 28 summarises the key differences between the four case studies.

Table 28: Comparison of case studies using stripping and/or scrubbing.

Case study	Feedstock for stripping/ scrubbing	Additives	Product
#4	Condensate from evaporation of RO concentrate	NaOH	Ammonia water (24% ammonia)
#19	Condensate from evaporation of RO concentrate	None	Ammonia water
#21	Liquid fraction of manure or digestate (AN) Sewage sludge digestate (AS)	HNO_3 or H_2SO_4	Ammonium nitrate or ammonium sulphate
#22	Manure	H_2SO_4	Ammonium sulphate

It should be noted that case studies #4 and #19 also produce a small volume of ammonium sulphate solution as a by-product of air scrubbing on exhaust air from manure processing operations. At case study #4, this spill water from the chemical air scrubber is explicitly sold as fertiliser. However, this stream originates from emissions control rather than deliberate nitrogen recovery from secondary raw materials, and its volume is small.

[83] Sigurnjak et al. (2019) Production and performance of bio-based mineral fertilizers from agricultural waste using ammonia (stripping-)scrubbing technology. *Waste Management*, vol. 89, pp. 265-274. https://doi.org/10.1016/j.wasman.2019.03.043
[84] Ehlert et al. (2019) Nitrogen fertilising products based on manure and organic residues. *SYSTEMIC project*. https://systemicproject.eu/wp-content/uploads/Factsheets-supporting-literature_nitrogen-fertilising-products.pdf
[85] SYSTEMIC (2021) Factsheet Waterleau NewEnergy (Ypres, Belgium). https://systemicproject.eu/wp-content/uploads/Factsheet-5-Waterleau-BE_20102021.pdf

7.2 Current production and maturity

Current production

Table 29 provides an overview of the ammonia stripping and scrubbing technology suppliers / installations that were found in literature[86,87]. There are more installations that treat wastewater, sewage sludge (Acqua & Sole, Veas WWTP, RVT Process Equipment) which have more than 50 installations worldwide for the recovery of ammonium sulphate via stripping and scrubbing.

Table 29: Overview of several ammonium sulphate (AS) and nitrate (AN) production installations via stripping and scrubbing in the EU27 and the UK, 2023 (source: Brienza et al. 2017[86] and ESPP 2023[87]).

Installation	Feedstock	Input per installation (kt/yr)	Product	N content	Nr of instal-lations
H2VOLAZ (IT)	Manure, digestate LF[a)]	11-44	AS	5-6% (AS)	4
Circular Values BV (NL)	Manure LF, digestate LF	8-60	AS or AN	7-8% (AS) 12-15% (AN)	15
Colsen (AMFER®) (NL/ES)	Poultry manure digestate	8-800	AS or AN	7.5% (AS) 15% (AN)	3
Detricon (BE/NL/ES)	Manure, digestate LF	16	AS or AN	8% (AS) 15% (AN)	4
Nijhuis/ Byosis (ByoFlex) (West EU)	Manure, digestates	Up to 640	AS	8.5% (AS)	25[b)]
Benas-GNS (DE)	Corn silage, poultry manure	75	AS (gypsum based)	~5% (AS)	1
RIKA Biofuels (UK)	Poultry manure	40	AS	40% solution	1

a) LF means liquid fraction; b) These 25 installations also cover installations treating sewage sludge centrate.

As visible in Table 29, most technologies are either focussed entirely on ammonium sulphate production or can do both ammonium sulphate and ammonium nitrate. The installations listed in Table 29 are located in Europe, including one in the United Kingdom, and are reported to illustrate the range of installed capacities and the suppliers active in the market. The production and market estimates in this section refer to the EU27.

The currently produced bio-based **ammonium sulphate** can be estimated by taking into account the capacities of the installations mentioned in Table 29. Based on available data, two providers (Circular Values BV and Colsen AMFER®) together recover approximately 2 t N/yr as ammonium sulphate solution from manure and digestate, corresponding to approximately 26 kt of product per year[87]. Including estimated contributions from the other suppliers, the total EU27 production of ammonium sulphate from manure and digestate feedstocks is estimated at approximately 0.05 – 0.1 Mt product per year.

The quantified current production of bio-based **ammonium nitrate** from standalone stripping and scrubbing of manure or digestate liquid fraction has not been systematically quantified at EU level. The technology is described as not yet widely introduced for manure and digestate feedstocks and real-life implementation beyond trials remaining limited[83,88]. Based solely on documentation from case study #21, who reports 4 currently active installations in Belgium, the Netherlands and Spain, processing an estimated average of 35,000 t input/yr per installation at a yield of 23.5 – 35.5 kg product/t. The current production of these installations is thus estimated at approximately 3.3 – 5.0 kt product/yr. There is one

[86] Brienza et al. (2017) Technical scheme and specification of the demonstration installation. https://systemicproject.eu/wp-content/uploads/D1.1-Factsheets-demoplants.pdf
[87] ESPP (2023) SCOPE Newsletter. https://phosphorusplatform.eu/images/scope/SCOPE_145_N-recovery.pdf
[88] VCM (n.a.). Ammonia stripping/scrubbing. https://www.vcm-mestverwerking.be/en/manureprocessing/11321/ammonia-stripping-scrubbing

other known commercial provider who operate similar installations. Their EU installation count and capacities are not publicly available. Total EU27 current production is therefore estimated at 0.02 Mt.

Maturity

The technology of ammonia stripping and scrubbing of ammonia is considered technically mature with full-scale applications in wastewater treatment and industrial applications. However, its specific use for the production of marketable ammonium sulphate (AS) or ammonium nitrate (AN) fertiliser from manure and digestate liquid fractions remains limited across the EU, with a small number of documented commercial installations, as shown in Table 28.

7.3 Feedstock-based production potential

The technologies from case studies #21 and #22 process livestock manure and the digestate liquid fraction. Livestock manure availability is estimated based on data from D5.1, namely the estimated collected manure from pigs and cattle. Since ammonia stripping and scrubbing works on liquid streams, the feedstock should be pumpable and have a sufficient ammonium concentration. Poultry manure is dryer than pig and cattle manure slurries. Even though poultry manure has high ammonium concentrations, it generally requires either dilution or digestion before the stripping and scrubbing process[89]. Therefore, this feedstock is excluded from the livestock manure availability for this analysis. The digestate availability is reported according to data stated in Table 7, which reports 135-142 Mt FM of digestate from manure, of which 11-41Mt is the solid fraction[25]. This gives a liquid fraction of 94-131 Mt.

To calculate the nitrogen content in livestock manure, an average nitrogen content of 5 kg/tonne manure is assumed for the pig and cattle manure[90,91]. As assumed in section 3.4, 30% of the nitrogen in whole digestate is assumed to end up in the solid fraction after solid-liquid separation. This indicates that 70% of the available nitrogen in whole digestate can be assumed to be present in the liquid fraction. As stated in Table 11, whole digestate consists of approximately 0.41% of nitrogen, thus giving a nitrogen availability in the liquid fraction of digestate from manure of approximately 0.40 Mt N.

Table 30: Theoretical feedstock availability and N content per feedstock stream in the EU27.

Feedstock	Theoretical feedstock availability (Mt)	N content in feedstock stream (Mt)
Livestock manure (pigs, cattle)	1,062	5.31
Digestate liquid fraction from manure	113	0.40
Total in Europe	**1,175**	**5.71**

For **ammonium sulphate**, the nitrogen recovery rate varies significantly depending on the technology configuration. The optimised full-scale systems with alkali dosing and heating can achieve up to 80-90% recovery. Simplified systems operating at lower temperatures without alkali dosing typically achieve 30-50% recovery[89]. Case study #22 reports a yield of 1.5% (t fertiliser per tonne input), which at a product N content of 5-6% (see Table 29), implies an N recovery of approximately 18%, giving an **ammonium sulphate feedstock-based production potential of 17.6 Mt.** This lower figure reflects the specific operating conditions of case study #22 and is used as the conservative estimate in Table 31, while the 80% recovery scenario represents the upper bound for highly optimised systems.

For **ammonium nitrate**, assuming an 80% stripping nitrogen recovery and 15% N content in the final product (see Table 29) gives an estimation for the produced quantities of ammonium nitrate, with a total

[89] Baldi et al. (2018) The Valorization of Ammonia in Manure Digestate by Means of Alternative Stripping Reactors. *Sustainability*, vol. 10, no. 9, pp. 3073. https://doi.org/10.3390/su10093073
[90] Fertilizer Association of Ireland (n.a.) Animal manures. https://www.fertilizer-assoc.ie/plant-nutrients/animal-manures/
[91] NRM (2021) Information Sheet: The Value of Manure and Slurry. https://cawood.co.uk/wp-content/uploads/2023/07/NRM-The-Value-of-Manure-and-Slurry.pdf

ammonium nitrate feedstock-based production potential of 30.5 Mt in Europe. The case study has provided an average yield of 23.5 – 35.5 kg fertiliser per tonne input. Applying this yield to the feedstock availabilities from Table 30 gives an estimated ammonium nitrate production of 27.2-41.0 Mt. The calculated 30.5 Mt production potential based on the above assumptions falls within this range.

Table 31: Theoretical production potential based on feedstock availability in the EU27.

Feedstock	Theoretical production potential of ammonium sulphate (Mt)	Theoretical production potential of ammonium nitrate (Mt)
Livestock manure (pigs, cattle)	15.9	28.3
Digestate liquid fraction from manure	1.7	2.1
Total in Europe	**17.6**	**30.5**

7.4 Applications and potential market size

Both ammonium sulphate and ammonium nitrate produced via stripping and scrubbing from manure or digestate may be eligible under the RENURE framework, provided that they meet the relevant product and quality criteria. The ammonium salts category in the directive cover products obtained by scrubbing ammonia from the off-gas generated during striping of liquid manure or digestate, the process applied in case studies #21 and #22. Therefore, in theory these products are RENURE eligible. Under the RENURE framework, the application of these products at up to an additional 80 kg N/ha/yr above the standard 170 kg N/ha manure limit are allowed, creating a direct pathway for the bio-based ammonium sulphate and ammonium nitrate to substitute the synthetic ammonium sulphate and ammonium nitrate.

7.4.1 Ammonium sulphate

The direct substitution market for bio-based ammonium sulphate is the current EU27 consumption of conventional ammonium sulphate. Conventional ammonium sulphate has a nitrogen content of 21% and a sulphur content of 24%, and its consumption as fertiliser in the EU27 in 2023 was 0.3 Mt N, or approximately 1.5 Mt in total[93]. The products from case study #21 and #22 are more dilute than the conventional product, containing approximately 8% and 5.5% nitrogen respectively. To supply the same amount of nitrogen as currently consumed in the EU27 as conventional ammonium sulphate, approximately 3.8 Mt of the case study #21 product or 5.6 Mt of the case study #22 product would be required, as shown in Table 32. This gives an average EU27 demand for bio-based AS equivalent of 4.7 Mt. The sulphur content of both bio-based products is also substantially lower than that of conventional ammonium sulphate, namely 9% and ~6% respectively, compared to 24%. This may limit direct substitutability in sulphur-deficient soils where the combined N and S supply of conventional ammonium sulphate is specifically important.

Table 32: Ammonium sulphate content and demand in the EU27.

	N content	S content	EU27 demand expressed as conventional AS (Mt)	EU27 demand expressed as bio-based AS equivalent (Mt)
Ammonium sulphate conventional	21%	24%	1.5	
Bio-based ammonium sulphate (case study #21)	8%	9%	-	3.8
Bio-based ammonium sulphate (case study #22)	5.5%	~6%*		5.6

* Sulphur content was not directly reported by case study #22, it was estimated from the stoichiometry of ammonium sulphate, giving a theoretical S:N ratio of 1.1.

7.4.2 Ammonium nitrate

Like ammonium sulphate, the direct substitution market for bio-based ammonium nitrate is the current EU27 consumption of conventional ammonium nitrate of 3.8 Mt (1.3 Mt N). To estimate the direct market potential, consumption rather than production is used as the market size indicator, as EU27 production is complicated by significant export volumes. Conventional ammonium nitrate (AN) fertiliser has a nitrogen content of 34%[92] and its consumption as fertiliser in the EU in 2023 was 1,3 Mt nitrogen, or 3.8 Mt in total[93]. The product from case study #21 with a NPK of 15-0-0 would thus require 8.6 Mt in total to supply the same amount of nitrogen, as shown in Table 33. This indicates that the bio-based product would need to be applied at roughly 2-3 times the volume of conventional ammonium nitrate to deliver the same nitrogen dose per hectare.

Table 33: Ammonium nitrate nitrogen content and demand in the EU27.

	N content	EU27 demand expressed as conventional AN (Mt)	EU27 demand expressed as 15-0-0 equivalent (Mt)
Ammonium nitrate conventional	34%	3.8	
Bio-based ammonium nitrate (case study #21)	15%	-	8.6

7.5 Scale-up potential

Table 34 summarises the scale-up potential for bio-based ammonium sulphate and ammonium nitrate production via ammonia stripping and scrubbing in the EU27. Market demand is expressed using the ammonium sulphate concentrations of case studies #21 and #22 (8% and 5.5) and the ammonium nitrate concentration of case study #21 (15%), reflecting the range of product concentrations achievable through different stripping and scrubbing process conditions. Case studies #4 and #19 recover ammonia as ammonia water rather than as a salt and are therefore not included in this estimate.

The scale-up potential is substantial for both products. The scale-up factors are far larger than those calculated for other products such as struvite and digestate solid fraction, reflecting that bio-based ammonium salt production via stripping and scrubbing is at very early stages of deployment relative to both its feedstock potential and potential market demand.

Table 34: Estimation of scale-up potential of ammonium sulphate and ammonium nitrate in the EU27. Source: estimation BTG based on several sources as mentioned in the text.

	Ammonium sulphate (Mt)	Ammonium nitrate (Mt)
A. Feedstock-based potential	**17.7**	**30.8**
- Livestock manure (pigs, cattle)	15.9	28.3
- Digestate liquid fraction from manure	1.8	2.0
B. Market potential	**4.7**	**8.6**
C. Total potential (minimum of A & B)	**4.7**	**8.6**
D. Current production	**0.1**	**0.02**
E. Potential to scale up (C - D)	**4.6**	**8.5**

[92] Mitchell (2017) Nutrient Content of Fertilizer Materials. https://www.aces.edu/wp-content/uploads/2018/11/ANR-0174_NutrientContentFertilizerMaterials_103119L-1.pdf
[93] IFA (2026) Databases and Charts. https://www.ifastat.org/databases/plant-nutrition

Scale-up factor	46	427

7.6 Barriers to scale up

Until the full implementation of the RENURE in national legislation, the key market advantage of the application above the 170 kg N/ha manure limit is not available, which limits the short term market compared to the conventional ammonium sulphate and ammonium nitrate. The bio-based products are also substantially more dilute than their synthetic counterpart, namely 5.5-8% N for ammonium sulphate and 15% for ammonium nitrate, compared to 21 and 34% respectively for conventional products. Higher application volumes are therefore required to deliver the equivalent nitrogen dose per hectare, with consequences for the transport and application costs. The bio-based products could also be further dried to increase the nitrogen content, but this comes with extra processing costs.

7.7 Conclusions and recommendations

Ammonia stripping and scrubbing in a technically mature technology, producing bio-based ammonium sulphate and ammonium nitrate from the liquid fraction of manure and digestate. Both products via stripping and scrubbing may qualify under the RENURE framework as ammonium salts, provided that the quality criteria are met. This would allow application above the standard 170 kg N/ha manure limit once the framework has been transposed into national legislation.

Despite these favourable conditions, deployment is still at an early stage, with the current EU27 production estimated at approximately 0.1 Mt ammonium sulphate and 0.02 Mt ammonium nitrate per year, which is significantly less than the estimated scale-up potentials of 4.6 Mt and 8.5 Mt respectively. The national transposition of the RENURE framework in the national legislation is needed to reach this scale-up potential.

Funded by the European Union

8 Slow pyrolysis to biochar

8.1 Introduction

Three case studies have been selected that convert woody biomass via slow pyrolysis to biochar. Biochar is a carbon rich, porous solid material that can improve soil structure, water retention and nutrient availability when applied as a soil improver.

Case studies #24 and #25 both use a continuous screw reactor system. Case study #23 uses their patented cyclonic reactor system developed by a Canadian company, which currently operates a commercial installation in Canada, no EU installation is operational at this time.

Case study #23 produces a 100% biochar from mostly clean wood, which is recommended to be blended at a maximum ratio of 25% by volume with compost, peat or soil to promote plant growth and improve soil properties[94].

Case study #24 combines slow pyrolysis of green waste to produce biochar with anaerobic digestion of food waste. The products, biochar and digestate, are formulated into a blended soil amendment product, which can additionally be enriched with nutrients before land application. Adding biochar to digestate can enhance the digestate stability and increase the capacity to retain water and preserve nutrients[95]. Additionally, case study #24 treats the syngas produced during the pyrolysis via biological methanation into biogas. The case study is currently seeking funding for projects in Spain using agricultural residues including straw and olive tree prunings as feedstocks.

Case study #25 operates a commercial installation in Germany, converting municipal green waste and pruning residues into EBC Premium certified biochar since 2016. The biochar is applied as soil substrate.

8.2 Current production and maturity

According to Biochar Europe, **74.8 kt of biochar was produced in Europe in 2023**, with an expected increased production capacity of 115 kt in 2024[96,97]. Another market analysis stated that the Europe biochar market was valued at 168 kt in 2025[98] for all applications, including animal feed, industrial applications, as well as in substrates and possibly direct application in soil. According to Market Research Future (2026) [99] the European biochar market has reached 180.5 kt in 2025, with animal farming as main application (70.1%, i.e. 128 kt), e.g. feed additives, bedding amendment, ammonia reduction. According to the same source, about 26.5 kt (14.7%) was applied in agriculture, e.g. soil conditioning and water retention.

Over 30 technology providers are active in the European market, which have approximately installed over 220 production facilities throughout Europe, with dozens of more projects scheduled for 2025. Currently, most capacity is in Scandinavia (28%), followed by Germany (26%) and Austria-Switzerland (16%).

Biochar can be produced from several technologies, like slow pyrolysis, gasification and hydrothermal carbonisation. Slow pyrolysis is estimated to be the dominant biochar production technology, with a worldwide market share of 56% in 2024[100]. One of the largest suppliers within Europe, has installed more than 55 pyrolysis plants worldwide[101].

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[94] Lange and Bertrand (2017) BiocharFX: Production with carbonFX technology, characterization and applications in potting soil related to plant production. *Engineering Conferences International.* https://dc.engconfintl.org/cgi/viewcontent.cgi?article=1015&context=biochar
[95] FENIX (n.a.) Project. https://project-fenix.eu/project/
[96] Biochar Europe (n.a) Europe's biochar network. https://www.biochareurope.eu/
[97] Sherrard (2024) EBI releases annual European Biochar Market Report. *Bioenergy International.* https://bioenergyinternational.com/ebi-releases-annual-european-biochar-market-report/
[98] Mordor Intelligence (n.a.) Europe Biochar Market Size and Share. https://www.mordorintelligence.com/industry-reports/europe-biochar-market
[99] https://www.marketresearchfuture.com/reports/europe-biochar-market-12694
[100] IMARC (2025) How big is the biochar market? https://www.imarcgroup.com/news/how-big-is-the-biochar-market
[101] PYREG (n.a.) The company. https://pyreg.com/company

The three case studies represent installations at different stages of maturity. Case study #25 has been operational since December 2016, producing approximately 300 t/a of certified biochar from 1,400 t/a of municipal green waste. Case study #24 is a pilot installation within an EU-funded project, processing 910 t/a of wood chips and not yet marketed commercially. Case study #23 is based on the commercial installation in Canada, which has been operational since 2016. This case study has since exported its technology globally, with a European plant planned for France but not yet commissioned.

8.3 Feedstock-based production potential

The feedstocks used in slow pyrolysis for biochar production are woody biomass materials such as the categories defined in D5.1, like forestry residues, non-hazardous post-consumer wood, residues from further wood processing and stumps. Case study #25 converts municipal green waste into biochar. Woody biomass dominated the market with 50% share in 2024, whereas other feedstocks like agricultural waste, animal manure and sewage sludge are used less[100]. For these case studies, we consider the feedstocks in Table 35 and their availability as stated in D5.1 for the EU27[127]. For the municipal green waste, the estimated garden waste generated is assumed. It should be noted that this is the garden waste generated, which can be not collected or collected mixed with other bio-wastes. This is therefore an upper bound of feedstock availability.

Under laboratory conditions, biochar yields from woody biomass range from 24-30% of dry input mass[102].In full-scale commercial operations, yields are somewhat lower due to feedstock moisture variability and process conditions. Based on case study #25, which achieves approximately 300 t/a biochar from 1,400 t/a input, a real-world yield of 21% is used as central estimate for this calculation. The feedstock availability of garden waste generated is in fresh matter (FM), therefore a dry matter content of approximately 50% is assumed. Taking this into account, the **theoretical biochar production potential based on feedstock availability for the EU27 is estimated at 16.6 Mt per year**. Since there are many competing uses for these feedstocks, and some feedstocks like stumps are not regarded sustainable, the real production potential will be substantially lower. It is estimated that maximally 10% of the theoretical feedstock availability could be made available for biochar production, this corresponds to **9.9 Mt feedstock, and 1.7 Mt biochar in the EU27**.

Table 35: Theoretical biochar production potential based on feedstock availability in the EU27.

Feedstock	Theoretical feedstock availability (medium mobilization scenario) (Mt)	Theoretical biochar production potential based on feedstock availability (Mt)
Garden waste generated (FM)	39.3	4.1
Forestry residues (DM)	37.4	7.9
Non-hazardous post-consumer wood	9.0	1.9
Residues from further wood processing	7.8	1.6
Stumps	5.0	1.1
Total in Europe	**98.5**	**16.6**
Estimated maximum availability for biochar production	10%	10%
Feedstock-based production potential	**9.9**	**1.7**

[102] Lee et al. (2013) Comparison of biochar properties from biomass residues produced by slow pyrolysis at 500°C. *Bioresource Technology*, vol. 148, pp. 196-201. https://doi.org/10.1016/j.biortech.2013.08.135

8.4 Applications and potential market size

Biochar has several possible applications. It can be used as animal feed or in industrial applications such as metallurgy and construction materials. However, for the scope of the FertiCovery project, only agricultural applications, i.e. in substrates, compost and direct application on agricultural land are considered.

Biochar is prominently promoted as way to store carbon in soil and products, and several voluntary carbon emission reduction schemes have been established (e.g. Puro Earth, BioCarbon standard, EBC, VERRA VCS) (IBI 2025)[103] to quantify these claims and make them tradeable as carbon credits. Moreover, an EU Carbon Removal Certification Framework (CRCF)[104] is under development, with a harmonised method to claim carbon removals from among others the application of biochar. The inclusion of biochar under Component Material Category 14 (CMC14) of the revised Fertilising Products Regulation, facilitates the use of biochar within the EU27.

Unlike the other products in this report (e.g. struvite, digestate, ammonium nitrate and ammonium sulphate), biochar does not replace something specific like a synthetic fertiliser with a defined market in kt N or kt P. It is a soil improver that should create its own demand. Thus, biochar does not replace fertilisers. Applying biochar on soils would result in an improved water retention, nutrient retention and soil structure. Specifically in the EU organic farming context it could be valued due to its improvement of soil health without synthetic inputs.

An important question remains whether direct application of biochar on agricultural land has sufficient agronomical value. JRC (2019)[65] reports on a study (Jeffery et al 2017)[105] based on 598 cases documented in 44 different studies from temperate regions, that observed that C-rich biochar amendment to soils in temperate regions significantly decreased crop yield relative to controls (i.e. soils that did not receive any fertilising materials) at a median biochar application rate of 30 t/ha. For temperate regions, only positive effects were observed at an application rate of 31-50 tonnes/ha. Jeffery et al. (2017) further indicated that many arable soils in temperate regions are moderate in pH, high in fertility, and generally receive high fertiliser inputs, leaving little room for additional benefits from C-rich pyrolysis & gasification materials (e.g. biochar). According to JRC (2019) their work indicated the positive impacts of the application of pyrolysis & gasification materials for soils with an organic C level < 1%. Although such soils are mostly absent in Europe (de Brogniez et al., 2015)[106], this observation may point towards the possible added value of pyrolysis & gasification materials in soil-less growing media.

JRC (2019), therefore, indicates the potential of biochar to be used as part of soil-less plant-growing media in horticulture, where they could possibly replace or complement other substrates like peat and lignite. According to JRC (2019) referring to EUBIA (2015) more than 200 kt of lignite is used directly as soil improver or growing media. This could be taken as a proxy for the potential for biochar in growing media. According to JRC (2019) further market uptake will depend on the interaction between economic and environmental concerns for the sector and the performance of biochar relative to the current materials used, including not only peat but also other alternatives such as compost, coir, softwood bark, wood fibre and wool. The German peat reduction strategy (BMEL 2022)[16] lists the use of peat alternatives like green compost, wood, cocos in 2021, but biochar is not listed, indicating no or low market uptake so far.

Apart from a considerable amount of scientific literature, no significant commercial application of biochar on agricultural soil were identified. As biochar does not replace N, P, K, it must find its own market as soil improver or part of a substance in growing media. One possible application is adding biochar to compost, as it may improve nutrient retention, water-holding capacity, soil structure, microbial activity and soil organic carbon levels, while also contributing to carbon sequestration. Crop yield may also be positively

[103] IBI (2025) A manual for biochar carbon removal, a comparative guide for the certification of biochar production as carbon sink, International Biochar Initiative. Link
[104] https://climate.ec.europa.eu/eu-action/carbon-removals-and-carbon-farming/carbon-removals-and-carbon-farming-crcf-regulation_en
[105] Jeffery S., Abalos D., Prodana M., Bastos A.C., van Groenigen J.W., Hungate B.A. & Verheijen F. (2017) Biochar boosts tropical but not temperate crop yields. Environmental Research Letters 12: 053001.
[106] de Brogniez D., Ballabio C., Stevens A., Jones R.J.A., Montanarella L. & van Wesemael B.
(2015) A map of the topsoil organic carbon content of Europe generated by a generalized additive model. European Journal of Soil Science 66: 121-134.

influenced in the end. This may also depend on production methods, feedstock, climate, and farm management practices.

Biochar Europe (2026) expects limited growth of biochar in agriculture[107], a high potential for application in building materials once regulatory barriers fall; relevant volumes and rapid growth in metallurgy, and steady growth in urban greening and substrates. It remains difficult to estimate future market potential of biochar for agricultural applications. As a rough estimate, based on the 26.5 ktonnes of biochar in agriculture as found in 2025, and the estimated average CAGR[108] of 22.1% for all biochar applications in Europe together between 2025 and 2035 (Market Research Future 2026)[99] , results in a **market potential of 195 kt biochar for agricultural use in 2035**, for which 1.9 Mt woody biomass is needed. In case biochar is strongly promoted by e.g. the market for carbon removal credits from corporate buyers seeking to offset their emissions with biochar carbon removal certificates, this estimation may be on the conservative side, but in that case the biochar application would not be primarily driven by agronomic demand.

8.5 Scale-up potential

The scale-up potential of biochar is summarised in Table 36. The current production includes biochar made for non-agricultural applications. The market potential may increase above the estimated 0.2 Mt/yr due a push to store biochar on agricultural soil.

Table 36: Estimation of scale-up potential of biochar for agricultural application in the EU27 (Mt/yr).
Source: estimation BTG based on several sources as mentioned in the text.

	Biochar (Mt)
A. Feedstock-based potential	**1.67**
B. Market potential	**0.20**
C. Total potential (minimum of A & B)	**0.20**
D. Current production	**0.03**
E. Potential to scale up (C - D)	**0.17**
Scale-up factor	6

8.6 Barriers to scale up

It is possible to produce biochar with a CE label, promoting trade throughout the EU. The direct application on agricultural soils seems to be limited due to limited agronomical advantages, and rather high production costs, that require parallel sales of the carbon emission offsets. A considerable amount of research can be found on blends of biochar to be mixed with compost and substrates, which may at some point result in increased market uptake. Inconsistent agronomic guidelines on particle size, feedstock origin, and crop-specific rates create variable field results that slow mainstream adoption[109]. Moreover, high biochar production costs are anticipated to be an important barrier to scale-up.

8.7 Conclusions and recommendations

Biochar has several possible applications, e.g. as component in animal feed, industrial applications. Within the EU current volumes in direct agricultural applications are limited. As biochar does not replace N, P, K, it must find its own market as soil improver or part of a substance in growing media. JRC (2019) found no convincing evidence that application of biochar in temperate regions, result in increased crop yield, and even found decreased crop yield at a median biochar application rate of 30 t/ha. The application

[107] European Biochar Market Report 2025 | 2026, 5th edition, June 23rd 2026.
[108] Compound Annual Growth Rate
[109] https://www.mordorintelligence.com/industry-reports/europe-biochar-market

of biochar in soils is mainly beneficial for soils with an organic C level < 1%, whilst such soils are mostly absent in Europe (de Brogniez et al., 2015).

Commercial opportunities are likely most promising in growing media, landscaping and urban greening, premium soil improvers and carbon farming schemes. The high production cost of biochar production form, as a major challenge to further scale-up, which may be compensated by income from the sales of carbon offsets, as biochar is seen as an important pathway to carbon removal, that will be further promoted by the CRCF-regulation.

9 Hydrolysis

9.1 Introduction

Hydrolysis is a process in which complex organic molecules are broken down into smaller compounds through a reaction with water. In nutrient recovery applications, hydrolysis is typically accelerated through the addition of acids, alkalis, heat or combinations of these. The process is used to convert complex organic matter such as proteins, carbohydrates, into simpler compounds that are more readily available for further processing (e.g. by anaerobic digestion) or direct agricultural use. Depending on the feedstock and process conditions, hydrolysis can produce a wide range of products, from amino acid concentrates, organo-mineral fertilisers and liquid fertilisers with biostimulant properties.

The four case studies assessed within this pathway demonstrate the diversity of products. Whilst all four of them rely on a chemical breakdown of organic matter, they differ in feedstock, operating conditions and final product. An overview of the four technologies is shown in Table 37 and described below. The current production related to case study #13 relates to installations located in North America. The feedstock-based potential presented later in this chapter is calculated on sewage sludge availability in the EU27, and therefore represents the potential for deployment of the technology in the EU rather than an extension of the existing production.

Table 37: Overview of case studies using hydrolysis.

Case study	Feedstock	Technology	Output[110]	Output production scale
#12	Sewage sludge biosolids	Acidic hydrolysis + volatile fatty acid distillation	Concentrated nutrient solution (biostimulant)	0.0007 kt/yr (700 kg/yr)
#13	Sewage sludge biosolids	Alkaline thermal hydrolysis	Liquid organo-mineral concentrate (NPK[b]: 0.7-1.1-0.4)	300 kt/yr (outside EU)
#14	Poultry feathers	Acidic hydrolysis	Liquid organo-mineral concentrate (NPK[a]: 2.8-0.35-3.9; S: 2.7)	0.13 kt/yr
#15	Food waste digestate, haemoglobin	Acidic hydrolysis	Granular organo-mineral (NPK[a]: 8.6-1.5-2.0)	0.0024 kt/yr

Case study #12 treats communal sewage sludge by combining acidification, phase modification and fractional distillation to recover volatile fatty acids (VFA). The resulting product is a concentrated nutrient solution marketed as a biostimulant. The product is sold in small volumes for ornamental plants and has been demonstrated on intensively managed lawns, such as golf courses and municipal parks, as well as on selected agricultural crops. The product is applied in highly diluted form and aims to stimulate nutrient uptake, plant vitality and soil biological activity rather than supplying crop nutrients.

Case study #13 treats dewatered biosolids from municipal, industrial and commercial wastewater by a physical-chemical thermal hydrolysis process to produce a liquid mineral concentrate. Raw sludge is generally first thickened and stabilised to reduce the odour and the number of pathogens, for example via aerobic digestion. This stabilised sludge, or also called biosolids, can either be incinerated, directly applied on land in some cases or treated further via treatment processes or amongst others, anaerobic digestion or composting. These biosolids are the nutrient-rich organic solid input material for the thermal hydrolysis process. The fertilising product, a liquid organo-mineral concentrate contains approximately 0.7-1.1-0.4 NPK on an as-applied basis and is primarily intended for agricultural use.

[110] Data obtained from a) questionnaires filled in by technology provider representative; b) literature.

Case study #14 applies acidic hydrolysis to poultry feathers, converting keratin-rich waste into a liquid organo-mineral fertiliser to improve crop growth, stress tolerance and crop quality. Similar to case study #12, the product is applied at very low rate.

Case study #15 combines hydrolysis, conditioning and granulation to upgrade digestate from food waste together with haemoglobin and mineral additives into a granular organo-mineral fertiliser. In contrast to the other hydrolysis pathways, the final product is a dry fertiliser with a nutrient content of approximately 8.6-1.5-2.0 NPK and is intended to supply nutrients to agricultural crops.

9.2 Current production and maturity

Current production

The current production numbers per case study differ substantially and reflect the different stages of development of the technologies, as shown in Table 37. Case study #13 is by far the most advanced pathway, with at least fourteen commercial installations operating in North America and additional installations under construction. Since its first full-scale deployment in 2004, more than 1.6 Mt product has been sold. Based on the currently installed capacity, annual production is estimated at approximately 0.3 Mt per year.

In contrast, case studies #12, #14 and #15 remain at pilot or early commercial scale. Case study #14 is the most commercially developed of these three pathways. It produces approximately 0.13 kt product per year and is commercially available in Poland. Case studies #12 and #15 operate currently only at very small scale, with annual production volumes below 3 tonnes per year. These technologies have primarily been demonstrated through a pilot installation.

Overall, the current hydrolysis-based fertiliser production within the EU remains limited. The only large-scale commercial case study identified is located outside the EU, indicating that hydrolysis is rather an emerging market than an established nutrient recovery pathway in the European fertiliser market.

Maturity

Hydrolysis itself is a mature process that is widely applied in sectors such as wastewater treatment, and food processing. The differences in maturity between the case studies therefore in all probability mainly relate to product development, market acceptance and commercial deployment, rather than the hydrolysis process itself.

Case study #13 is a mature and commercially proven technology with multiple full-scale installations. On the other hand, case studies #12, #14 and #15 are at an earlier stage of market development and all have one installation. In general, while the individual process steps within these case studies are relatively well-established technologies, such as stabilisation, thermal treatment and fertiliser granulation, their integration into a hydrolysis-based fertiliser production process is still under development.

9.3 Feedstock-based production potential

The feedstock-based production potential of the hydrolysis technologies depends on the availability of the respective feedstocks. Since hydrolysis can be applied to a broad range of secondary raw materials, the theoretical production potentials differ substantially between the assessed case studies.

Case studies #12 and #13 both utilise sewage sludge originating from wastewater treatment plants. As reported in D5.1, approximately 6.1 Mt of sewage sludge dry matter was generated in the EU in 2023. Applying the conversion factors of case study #12 for the production of a concentrated nutrient solution, results in a theoretical production potential of approximately 11.4 kt product per year[111]. In contrast, case study #13 converts the majority of the biosolids into a liquid organo-mineral concentrate. Assuming that approximately 95% of the incoming dry matter remains in the product and considering a final dry matter

[111] Bora et al. (2020) Sewage sludge to bio-fuel: A review on the sustainable approach of transforming sewage waste to alternative fuel. *Fuel*, vol. 259, pp. 116262. https://doi.org/10.1016/j.fuel.2019.116262

content of 13-16%, the resulting feedstock-based production potential is estimated at 34-42 Mt FM/yr. This significantly larger volume compared to #12 is explained by the fact that this thermal hydrolysis step does not separate the nutrients but rather produces a liquid mineral concentrate product with lower nutrient concentrations than the product of case study #12.

Case study #14 applies hydrolysis to poultry feathers, as determined in D5.1, approximately 0.7 Mt poultry feathers are generated annually in the EU. Based on the reported product yield, this corresponds to a theoretical feedstock-based production potential of approximately 0.6 Mt per year.

Case study #15 uses digestate from food waste digestion together with haemoglobin and various mineral additives. According to the EBA, approximately 17-18 Mt of food waste digestate is produced annually in the EU[25]. Based on the reported formulation and product yield, this corresponds to approximately 22 Mt granular organo-mineral fertiliser per year. It is important to note that this estimate assumes availability of all required inputs, including 10 Mt/yr haemoglobin and 5 Mt/yr peat.

Table 38: Overview of feedstock-based availabilities per hydrolysis case study, based on EU27 feedstock availability.

Case study	Feedstock	Total feedstock availability (Mt feedstock)	Theoretical feedstock-based availability (Mt product)
#12	Sewage sludge	6.1 (DM)	0.011
#13	Sewage sludge	5.8 (DM)	38 (34-42)
#14	Poultry feathers	0.699[a)]	0.604
#15	Food waste digestate	17-18[25]	22

a) D5.1

As visible in Table 38, the feedstock-based production potentials of the case studies differ significantly, ranging from 11 kt/yr to over 40 Mt/yr, reflecting the different product concepts and conversion yields.

9.4 Applications and potential market size

The applications and market potential of the hydrolysis-derived products differ substantially between the four case studies. The produces assessed range from low-dose liquid organo-mineral fertilisers intended to enhance plant growth and stress tolerance, to other organo-mineral concentrates intended to supply quantities of nutrients. Consequently, a single market assessment approach is not appropriate for all hydrolysis pathways.

Three product categories can be identified: organo-mineral concentrates with biostimulant properties (case studies #12 and #14), liquid organo-mineral concentrate used as fertiliser (case study #13), and granular organo-mineral fertiliser (case study #15). For each category, the potential market size was estimated based on the most relevant agricultural applications, production functionality and typical application rates.

9.4.1 Organo-mineral fertiliser with biostimulant properties

Case studies #12 and #14 produce liquid organo-mineral concentrates that are applied as fertilisers at low dosages and primarily aim to stimulate plant growth, nutrient uptake and resilience to stress. Unlike other fertilisers, these products are not intended to satisfy the nutrient demand of the plant.

The most plausible potential market segments for **case study #12** are intensively managed applications, including golf courses, stadium pitches, or ornamental applications, municipal landscaping and consumer gardening. For these applications, small product volumes combined with perceived plant health benefits may justify a higher cost per unit nutrient supplied. In contrast, large-scale use for agricultural purposes is considered unlikely due to the low nutrient concentrations in the product.

Table 39: Market demand calculation for case study #12.

Market estimation		Estimated market demand for case study #12 (kt)
Turf and landscaping demand for lawns	*Dilution 1:50, weekly during vegetation season (5 months), 15 L solution/ha/yr*[112]	**7.0**
Golf courses	6,700 golf courses, 134 thousand ha intensively managed area in EU[113],[114].	2.0
Stadium pitches	1,170 professional football clubs[115], 0.71 ha on average, total 831 ha.	0.012
Municipal lawns	5% urban areas in EU[116], 46% urban greenery[117], 70% lawns[118], total 6,641 ha, adoption rate 5%	5.0
Consumer gardening	*Dilution 1:1000, every two weeks, 10 L solution/ha/yr (assumption)*[119]	**0.9**
Consumer gardens	20% of urban greenery are private gardens[120], 1,898 thousand ha, adoption rate 5%	0.9
Total market demand		**8.0**

Although the product from **case study #14** could in theory be applied to a wide range of agricultural and horticultural crops, amino-acid based biostimulants are primarily relevant for higher-value crop segments such as vegetables, fruit, vineyards and horticulture, where the additional costs can be justified by crop value and quality improvements. Based on Eurostat data, approximately 8 million ha in the EU is assumed to represent this addressable crop area. The product is applied foliar, at a dilution of 0.2-0.5 L per 100 L water. Assuming a spray volume of 500 L/ha (confirmed by questionnaire input), this corresponds to an annual application rate of approximately 6-15 L/ha. With an assumed adoption rate of 5% of the addressable crop area, the potential market demand for the product from case study #14 is estimated at approximately 4.2 kt per year.

9.4.2 Liquid organo-mineral concentrates used as fertilisers

The product from **case study #13** is a liquid organo-mineral concentrate that can be applied according to traditional liquid fertiliser processing, handling and application equipment. It is commercially sold only in North America, where it complies with the Canadian Fertilizers Act and is regulated as Class A biosolids fertiliser in the US. The mineral concentrate product is mainly sold to nearby farmers close to the plants in North America. The product can also be returned to anaerobic digesters where it gives an increased biogas yield. The hydrolysed biosolids liquid mineral concentrate has a N-P-K content of 4.5 – 7 – 2.5 on dry matter

[112] COMPO EXPERT (2023) Turf product guide. https://compo-expert.com/sites/default/files/2023-06/COMPO%20EXPERT%20UK%20Brochure-2023.pdf. Compared with Basfoliar liquid biostimulant (p.42-45)
[113] M. Strandberg (2025) Multifunctional golf courses: an underutilised resource. Sterf. https://sterf.org/wp-content/uploads/2025/01/STERF_MULTIFUNK_EN_1.pdf. This source states that for an 18-hole golf course, around 20 ha are intensively managed active playing areas.
[114] Statista (2026) Number of official golf courses in Europe from 1985 to 2018. https://www.statista.com/statistics/275309/number-of-golf-courses-in-europe/
[115] European Leagues (n.a.) The European Leagues in Numbers. https://europeanleagues.com/
[116] Copernicus Land Monitoring Service (n.a.) Urban Atlas. https://land.copernicus.eu/en/products/urban-atlas. With a total land of EU pf 4,125 million km^2 according to Eurostat (2026) Land use overview by NUTS 2 region. https://ec.europa.eu/eurostat/databrowser/view/lan_use_ovw__custom_20557829/default/table
[117] Husqvarna (2025) Urban Greece Space Report 2025. https://hugsi.green/whats-new. Urban green spaces include parks, lawns, forests and natural vegetation.
[118] M. Ignatieva et al. (2015) Lawn as a cultural and ecological phenomenon: A conceptual framework for transdisciplinary research. Urban Forestry & Urban Greening, vol. 14, no. 2, pp. 383-387. https://doi.org/10.1016/j.ufug.2015.04.003
[119] Following the application guide, a dilution ratio of 1:1000 is assumed, which means that the biostimulant concentration is 0.1% in the final spray liquid, if the field spray volume were 500 L/ha per application, that would equal 0.5 L biostimulant/ha per application, with over 20 applications, that becomes 10 L/ha/year.
[120] Davies et al. (2009) Mapping an urban ecosystem service: Quantifying above-ground carbon storage at a city-wide scale. Journal of Applied Ecology, vol. 48, no. 5, pp. 1125-1134. https://doi.org/10.1111/j.1365-2664.2011.02021.x

or total nutrient basis. Dried municipal sewage sludge has approximately the same NPK, namely 5 – 6 – 0.5[121]. On an "as applied" basis (thus, in liquid form), this translates to approximately a NPK of 0.7 – 1.1 – 0.4 (with 16% DM). Compared to conventional mineral liquid fertilisers, these are low nutrient contents.

The main market will be the agricultural sector. Because the regulatory acceptance and agronomic use of the hydrolysed product are expected to be comparable to conventional sewage sludge application, the potential market size was further constrained to the current scale of sludge usage in agriculture. Therefore, it is assumed that this product is only applicable in countries where sewage sludge is still applied for agricultural purposes. The total amount of sewage sludge applied in 2023 in the EU in the agricultural sector was 2 Mt DM, corresponding to 41 Mt wet sewage sludge[64].

This sludge-treatment technology is, as stated, typically supposed to be implemented at large-scale WWTP due to sizing. EU reporting under the Urban Waste Water Treatment Directive indicates that a relatively small number of plants above 10,000-100,000 p.e. treat the majority of wastewater. Based on its liquid form and its current application solely at neighbouring farms around the WWTP, a market penetration of 5% of the current sludge application volume was assumed. This resulted in an adjusted market potential of 2 Mt of hydrolysed biosolids mineral concentrate.

9.4.3 Granular organo-mineral fertiliser

The product from case study #15, due to its granular form, low moisture content and higher nutrient concentration, the product can be handled, stored and transported rather similarly to conventional organo-mineral fertilisers.

The granular organo-mineral fertiliser from **case study #15** has a reported NPK of 8.57 – 1.48 – 2.02 on fresh matter basis, and directly as an as-applied composition (moisture <5%). At the reported application rate of 1.2 t/ha, this fertiliser supplies approximately 103 kg N/ha, 18 kg P/ha and 24 kg K_2O/ha. With field trials on maize reported, maize is taken as main agricultural application. The typical maize requirement in the EU is around 50 kg N/ha, 55 kg P/ha and 175 kg K/ha[122,123]. The product should therefore be considered a supplementary organo-mineral fertiliser rather than a complete stand-alone maize fertiliser, particularly because the potassium supply is much lower than typical maize potassium requirements. Therefore, an adoption rate of 2% is assumed, also considering the granular nature of the product, gives an estimated theoretical market demand of 154 kt/yr.

9.5 Scale-up potential

Table 40 summarises the scale-up potential for the four hydrolysis case studies. The feedstock-based potentials vary across the case studies, from 11.4 kt to 38,209 kt, which reflects the different product concepts, conversion yields and feedstock volumes involved. In all four cases, the market potential is the binding constraint rather than feedstock availability, confirming that scale-up is limited by market development rather than availability of secondary raw materials.

Case study #13 has the largest scale-up potential in absolute terms at 1,736 kt, reflecting its commercial maturity and large volume of sewage sludge available as feedstock. Case studies #12 and #14 have very small absolute scale-up potentials, consistent with their positioning as niche products with biostimulant properties, targeting high-value sectors. Case study #15 shows a scale-up potential of 154 kt with a very large scale-up factor which almost entirely reflects the extremely low current production of less than 3 tonnes per year, rather than a large absolute scale-up opportunity. This figure should therefore not be interpreted as a near-term realistic projection.

[121] Mitchell (2017) Nutrient Content of Fertilizer Materials. https://www.aces.edu/wp-content/uploads/2018/11/ANR-0174_NutrientContentFertilizerMaterials_103119L-1.pdf
[122] AHDB (n.a.) Maize crop nutrition. https://ahdb.org.uk/knowledge-library/maize-crop-nutrition
[123] Ludemann, Gruere, Heffer, and Dobermann (2022) Global data on fertilizer use by crop and by country. https://doi.org/10.5061/dryad.2rbnzs7qh

Table 40: Estimation of scale-up potential of hydrolysis case studies in the EU27 (kt/yr).
Source: estimation BTG based on several sources as mentioned in the text.

	#12 (kt)	#13 (kt)	#14 (kt)	#15 (kt)
A. Feedstock-based potential	**11.4**	**38,309**	**604**	**22,078**
- Urban WWTP sewage sludge	11.4	38,309		
- Poultry feathers			604	
- Digestate from food waste				22,078
B. Market potential	**8.0**	**2,036**	**4.2**	**154**
Turf and landscaping demand	7.0			
Consumer gardening	0.9			
Sewage sludge replacement		2,036		
Vegetables, fruit, vineyards, horticulture			4.2	
Maize				154
C. Total potential (minimum of A & B)	**8.0**	**2,036**	**4.2**	**154**
D. Current production	**0.0007**	**300**	**0.1**	**0.0024**
E. Potential to scale up (C - D)	**8.0**	**1,736**	**4.1**	**154**
Scale-up factor	11,359	6	32	64,230

9.6 Barriers to scale up

The barriers to scale up differ between the four case studies but share several common themes. For case study #12 and #14, which produce biostimulant products, the primary barriers are the high cost per unit nutrient relative to conventional fertilisers, which limits adoption to high-value crop segments. For case study #12 and #13 specifically, the possible presence of PFAS and PAHs in sewage-sludge derived products may restrict application possibilities and market acceptance. For case study #13, the primary barriers are the absence of CE marking under the EU Fertilising Products Regulation, although thermal hydrolysis is accepted under the FPR for precipitated phosphate salts under CMC12, the liquid organo-mineral concentrate produced through alkaline thermal hydrolysis of biosolids is not classified as a precipitated phosphate salt and would need to be marketed under national legislation as fertiliser. The low nutrient concentrations of the product mean that large transport volumes are required, limiting the economic viability of supplying farms beyond the immediate vicinity of the WWTPs. Regulatory acceptance of sewage-sludge derived products in agriculture also varies significantly between member states.

For case study #15, the primary barrier is the unrealistic additive requirement: the reported formulation requires approximately 10 Mt/yr of haemoglobin and 5 Mt/yr of peat to process EU food waste digestate at full potential. This fundamentally limits the scalability of the process beyond its current pilot scale.

Additional barriers across all case studies include the non-uniform composition of digestate and sewage sludge batches, the potential presence of heavy metals, micropollutants, drug residues and pathogenic microorganisms in sewage-sludge derived products, and the general early market development for novel hydrolysis-derived fertilising products in the EU.

9.7 Conclusions and recommendations

The four hydrolysis case studies represent a diverse range of technologies converting organic residues, sewage sludge, poultry feathers and food waste digestate, into bio-based fertilising organo-mineral fertilising products. In all four cases, market demand rather than feedstock availability is the binding constraint on scale-up, and the technologies are at early or niche commercial scale within the EU. Case study #13 is the exception in terms of maturity but is entirely absent from the EU market. Compared to dried sewage sludge, this hydrolysed liquid organo-mineral concentrate product is sanitised and in liquid form such that it is pumpable and injectable in agricultural systems. It targets agricultural farms with already existing liquid fertilising systems.

The primary recommendations to support scale-up across the four pathways are to pursue CE marking under the EU Fertilising Products Regulation for case studies #13, #14 and #15, since for sewage-sludge derived products it is an important market enabler.

10 Plasma process to nitrogen-enriched manure slurry

10.1 Introduction

Case study #16 (N2 Applied) uses a plasma-based technology to enrich livestock manure, specifically cattle manure, and digestate with nitrate to produce a nitrogen-enriched organic (NEO) fertiliser, here called nitrogen-enriched manure slurry. The manure/digestate is first separated in a solid and liquid fraction, after which the liquid manure/digestate can be pumped and treated in this installation in a batch process. The process doubles the nitrogen content of the organic inputs.

The estimated N content in the nitrogen-enriched manure slurry is approximated at 0.7% N on a fresh matter basis, compared to about 0.3-0.6% of average cattle slurry.

10.2 Current production and maturity

Current production

Between 2020 and 2022, at least 11 farm-scale pilot projects were launched in Norway, Denmark, Sweden, the Netherlands, and the UK using cow manure, pig manure, or digestate. Each treated 5–15 m^3 per day, equal to about 50–200 cows. 50 cows was considered the minimum viable scale, 150-200 cows a more realistic market. In 2023, units were installed at four dairy farms for a year-long analysis after partnering with a technology supplier. In March 2025, the company filed for bankruptcy[124]. Assuming that these farm-scale pilot projects are still operational, this would give an assumed current production of 30 kt/yr.

The technology is presented in a containerised unit with a fixed treatment capacity. Increasing the size of the individual reactors is not possible, but a higher capacity can be achieved by installing multiple units in parallel.

The scale up in numbers is primarily determined by the number of livestock farms and digestate plants for which nitrogen losses and emissions are probably a regulatory constraint, rather than by overall nutrient demand. Therefore, actual deployment of the technology is expected to concentrate in regions with high livestock density and nitrogen reduction targets. In this context, a scale up in numbers is expected to occur selectively rather than broadly.

Maturity

Enriching livestock manure with plant-available nitrogen by plasma treatment is a relatively new technology and, to our knowledge, there is only one supplier of plasma-treated manure/digestate systems. Other systems can create fertilisers via plasma processes through the conversion of air and water, but not by enriching manure or digestate. This enrichment of manure with nitrogen has been proven by the case study. Additionally, ammonia emissions during storage and field application show a reduction compared with raw manure and methane formation during storage was eliminated completely[125]. The produced nitrogen-enriched manure slurry shows a comparable or slightly improved yield compared with untreated manure[126].

[124] DN (2025) Milliardærenes prestisjestartup konkurs. https://www.dn.no/teknologi/n2-applied/konkurs/frode-strand-nielsen/milliardarenes-prestisjestartup-konkurs/2-1-1797982
[125] Nyvold M and Dörsch P (2024) Complete elimination of methane formation in stored livestock manure using plasma technology. Front. Sustain. Food Syst. 8:1370542. doi: 10.3389/fsufs.2024.1370542
[126] Cottis T., Mousavi, H. and Øivind Solberg, S. (2025) Plasma treated cattle slurry with modest fertilizer effect on grass. European Journal of Agronomy. 168:127649. doi: 10.1016/j.eja.2025.127649

These full-scale pilots, including multi-year farm trials to evaluate amongst others, the environmental benefits and the fertiliser performance, indicate that this technology can be classified in TRL 7-8. The technology has not been successfully commercialised.

10.3 Feedstock-based production potential

The system is mostly relevant for medium/large farms, since the capacity of one unit is about 3,000 to 4,000 tonnes/yr, which corresponds to approximately 50-200 cows[127]. With an average digestate yield of 94% from feedstock, which mostly consist of liquid fraction (94%), the AD plant should have a capacity of 3,400 to 4,500 tonnes per year to match the plasma unit requirements and produce 3,000 to 4,000 tonnes liquid digestate per year. Comparing this sizing to average digestate plants, would categorise this as a small-scale/farm-scale AD installation, therefore it is assumed that roughly all AD plants are suitable for instalment of a plasma-based unit.

The total availability of cattle manure and digestate from manure digestion has been calculated in D5.1 (884 – 1,313 million tonnes). This case study operates at farm scale and requires continuous slurry supply. One plasma treatment unit has a treatment capacity corresponding to roughly 50-200 dairy cows, depending on, amongst others, housing systems and operating time of the unit. With the data from D5.1, there are approximately 340 thousand holdings with this dairy farm size, corresponding to about 35% of all farms. These farms produce approximately 586 – 870 million tonnes manure annually.

Table 41: Feedstock-based potential of plasma process in the EU27.

Feedstock	Feedstock-based potential (Mt)
Cattle manure at farms ≥30 ha	586 – 870
Digestate from manure digestion	96 – 135
Total	**682 – 1,005**

This feedstock-based potential represents the theoretical volume of manure and digestate that could be treated if plasma technology were widely deployed across farms of suitable scale.

10.4 Applications and potential market size

Application

The product has the same physical properties of standard slurry, but with near doubling of the mineral content. Therefore, farmers can keep utilising existing agricultural machinery for the distribution.

Potential market size

The potential market for this nitrogen-enriched manure slurry is not primarily driven by nitrogen demand, but by the incentive to reduce nitrogen losses and GHG emissions from livestock manure storage and application, and to reduce dependence on supplementary synthetic nitrogen fertiliser[128]. As demonstrated in a cereal experiment reported by case study #16, plasma treatment allowed farmers to substitute approximately 95 kg N/ha of synthetic mineral fertiliser while achieving comparable crop yields[129].

However, given that the sole known technology supplier filed for bankruptcy in March 2025, the technology is still in early stages of commercialisation (TRL 7-8), and that the product remains classified as livestock manure under all current EU regulations and therefore provides no regulatory advantage over untreated manure, near-term market deployment is expected to be very limited.

[127] van der Voort and Vis (2025) Technical availability of feedstock supply, FertiCovery D5.1. Assuming a manure production per cattle of 18.3 tonnes/year.
[128] WUR (2025) Wageningen World February – Peddling manure. https://www.wur.nl/en/longread/peddling-manure
[129] Cottis, Mousavi and Solberg (2023) Plasma Treated Cattle Slurry Moderately Increases Cereal Yields. Agronomy, vol. 13, no. 6, pp. 1549. https://doi.org/10.3390/agronomy13061549

Functionally speaking, it could compete with the mineral nitrogen fertilisers that are applied in addition to manure. As stated during the feedstock-based potential discussion, only 35% of all farms are relevant for this technology (213 thousand holdings with 30-99 ha; 128 thousand holdings with > 100 ha). Assuming these lower farm size bounds results in 19.2 million ha available dairy farmland. Fertilizers Europe reports that 68% of the agricultural land is fertilised[130]. Applying this to the 19.2 million ha land, would indicate 13.0 million ha is fertilised and applicable for this technology.

The regions where there is a manure surplus are most probable to use such a technology, therefore it is assumed that, on top of the 35% eligible farms, 25% of all cattle manure is surplus at farms of sufficient scale. Given the bankruptcy, the maturity level, the significant electricity requirement and the regulatory absence, a conservative deployment fraction of 0.1% is applied, which reflects that only a small fraction of eligible farms would be interested in producing and using this nitrogen enhanced manure slurry.

Applying a conservative deployment assumption of 0.1% of eligible cattle manure surplus regions, where regulatory pressure creates the strongest incentive for nitrogen efficiency improvements, gives an indicative market demand of 0.08 Mt.

10.5 Scale-up potential

Table 42 summarises the scale-up potential for nitrogen-enriched manure slurry via plasma treatment of manure or digestate in the EU27. The feedstock-based potential of 843.5 Mt represents the theoretical maximum if plasma technology were widely deployed across all suitable dairy farms, but should not be interpreted as a near-term realistic potential. The market potential of 0.08 Mt is derived by assuming 25% of produced cattle manure in the EU is in regions with a manure surplus. Additionally, farms of sufficient scale are required and a conservative 0.1% adoption rate is applied, which reflects the bankruptcy of the sole known technology supplier in 2025, the TRL 7-8 maturity level and the absence of any regulatory advantage over untreated manure. Since market demand is the binding constraint, the scale-up potential is estimated at 0.05 Mt, with a scale-up factor of 1.7.

Table 42: Estimation of scale-up potential of nitrogen-enriched manure slurry in the EU (Mt/yr). Source: estimation BTG based on several sources as mentioned in the text.

	Nitrogen-enriched manure slurry (Mt)
A. Feedstock-based potential	**843.5**
- Cattle manure at farms ≥30 ha	728.0
- Digestate from manure digestion	115.5
B. Market potential	**0.08**
C. Total potential (minimum of A & B)	**0.08**
D. Current production	**0.03**
E. Potential to scale up (C - D)	**0.05**
Scale-up factor	1.7

10.6 Barriers to scale up

A key barrier for scale up is the significant electricity requirement of the plasma process. Current units require an electrical connection in the order of approximately 50 kW per unit, with reported energy consumption of approximately 0.33 kWh per litre produced NEO fertiliser. Additionally, uncertainties remain regarding the stability of the NEO fertiliser, particularly during extended storage periods and winter

[130] Fertilizers Europe (2024) Forecast 2024-2023. https://www.fertilizerseurope.com/wp-content/uploads/2024/12/Forecast-2024-34-web.pdf

conditions. As the product remains a liquid slurry, it is unsure whether the enhanced nitrogen content will be fully retained over time or that nitrogen losses might occur. Additional operational challenges remain such as foaming in tanks and the regular maintenance required of the plasma torch, making long-term continuous operation a challenge. Initial estimates also suggested that the system may be cost-prohibitive without substantial carbon credit incentive.

At this moment, there is no known CE-marked product comparable to this technology on the market. In the future, to qualify as “processed manure” under the FPR, the technology supplier must, amongst others, ensure processing to the Animal-by-product end point (including 70°C for at least 1 hour) and follow additional conditions, as stated in the Delegated Regulation 2024/1682[131]. If the product is not placed on the market but used on the farm, stored in manure storage and applied with the same equipment, the FPR does not apply. Under the Nitrates Directive, the definition of livestock manure includes manure in processed form, unless a MS has made an exemption for a specific category (e.g., RENURE). Therefore, at the EU level, plasma-treated slurry will still be classified as "manure" according to the Nitrates Directive, meaning it must adhere to the application limits and timing regulations for manure.

10.7 Conclusions and recommendations

Plasma-based enrichment of cattle manure to produce nitrogen-enriched manure slurry is a novel technology, demonstrated at farm scale but not successfully commercialised. The technology shows theoretical agronomic advantages, to reduce GHG emissions during manure storage, reducing nitrogen losses during application and substituting supplementary synthetic nitrogen fertiliser, but it faces fundamental barriers that limit scale-up. Most critically, the sole known technology supplier filed for bankruptcy in March 2025, leaving no commercial pathway for new installations. Unlike RENURE-classified products such as mineral concentrate and ammonium salts, plasma treated slurry remains classified as livestock manure under EU legislation, providing no additional application room and therefore limiting the economic incentive for farmers to invest. The scale-up potential is estimated at 0.05 Mt.

To support further scale-up, the primary recommendations are to first continue or re-start the development and demonstration of the technology by a new supplier, and to investigate a regulatory pathway that could classify nitrogen-enriched manure slurry as a processed product distinct from raw manure. Targeted deployment in regions with the strongest regulatory pressure on nitrogen management, particularly in the Netherlands could offer the most promising market entry point, where expiring cattle derogations and acute manure surplus pressure create the strongest farmer incentive to improve nitrogen efficiency per cubic meter of slurry applied.

[131] EU (2024) C/2024/1309. http://data.europa.eu/eli/reg_del/2024/1682/oj