BIOPART

SI Baltic Sea Neighbourhood Programme

Workshop 4
Topic “Development of digestate for the fertilizer market in the Baltic Sea Region”

Technological and operational aspects of digestate as fertilizer

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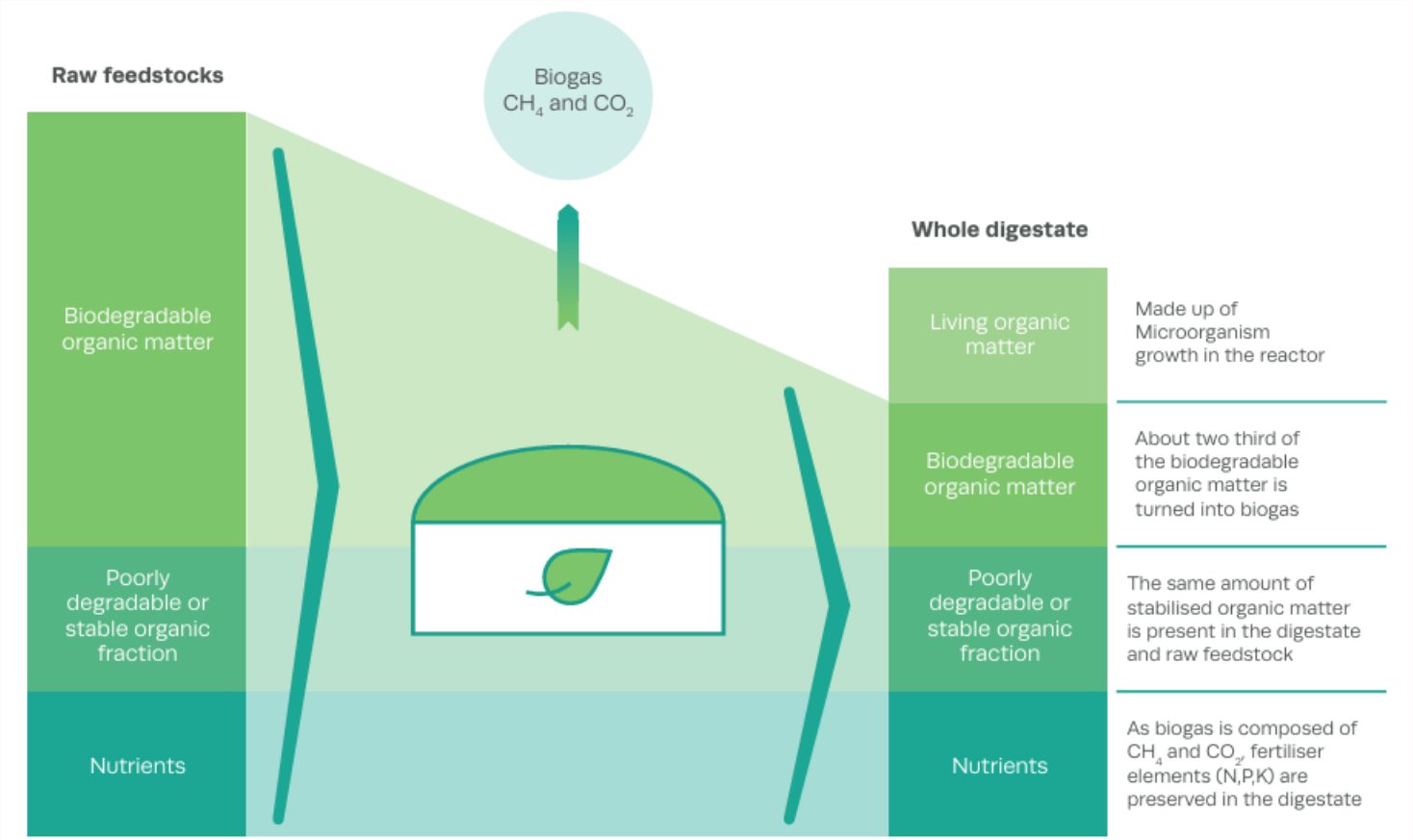
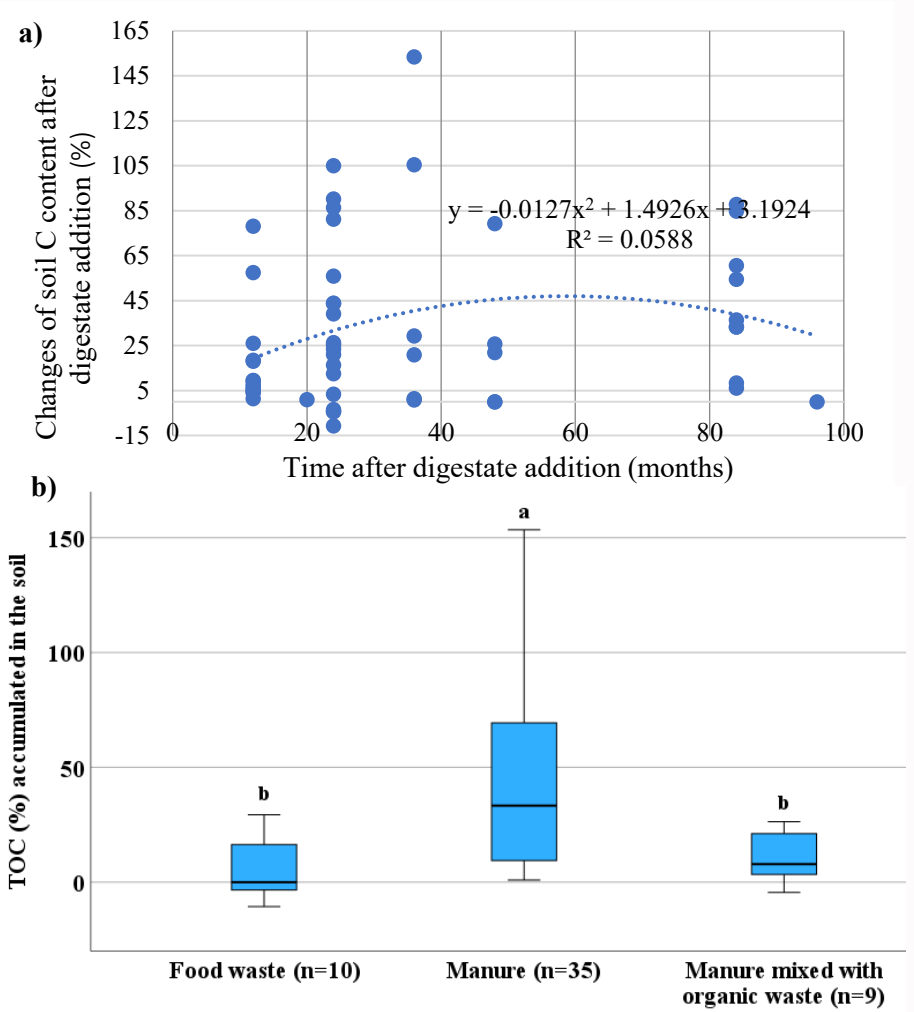
Formation of digestate and value of its organic matter for soil



What happens in the digester?

Source: *EBA. Exploring digestate's contribution to healthy soils, 2024.*



Accumulation of the total organic carbon (TOC) in the soil after more than 12 months of digestate addition (a), including different digestate substrate sources (b)

Source: *Ablieieva et al., 2025, https://doi.org/10.57647/ijrowa-k96c-rj49*

Typical composition of digestate

Average nutrient composition of agricultural and biowaste-based digestate, according to literature review (source: EBA Statistical Report 2023)

	DM g/kg FM	TOC g/kg DM	TKN g/kg DM	N-NH4 g/kg DM	P g/kg DM	K g/kg DM	Ca g/kg DM	Mg g/kg DM
Agricultural	57	297	67	34	14	9	16	5
Biowaste	n.a.	227	46	36	8	27	3	18

Changes in the average composition of the manure of dairy cows after fermentation (mesophilic mode for 52 weeks)

	TS g/Kg	**N_{tot}** g/Kg	**NH_4-N** g/Kg	**NH_4-N** % N_{tot}	**pH** -
Feedstock (cattle manure)	72,2	3,5	2	67	7,4
Digestate	59,3	3,6	2,4	80,5	7,9
Difference	- 17,9%	+ 2,8%	+ 20%		

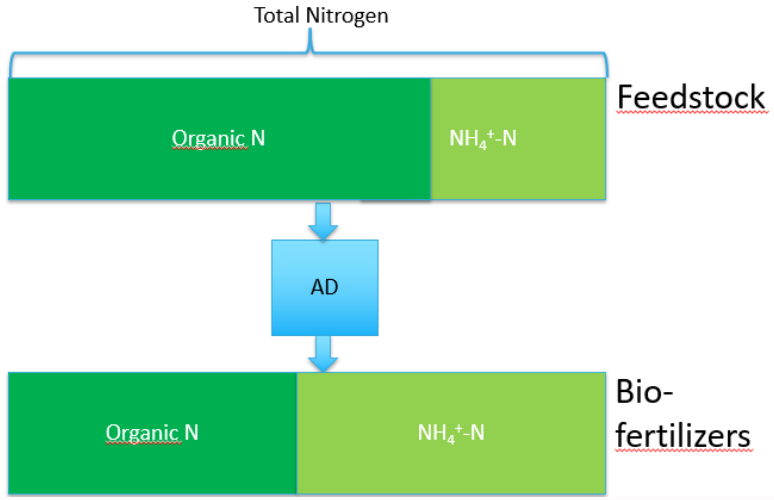
Typical dry matter (DM) and nutrient contents of digestates

Source: Digestate use on Scottish Farms

Digestate type	DM[1] (%)	RAN[2] (%)	kg/t (solids) or kg/m³ (liquids) Total N	P_2O_5	K_2O	SO_3	MgO
Food-based, whole	4.1	79	4.8	1.1	2.4	0.7	0.2
Food-based, separated liquor	3.8	89	4.5	1.0	2.8	1.0	0.2
Food-based, separated fibre	27	25	8.9	10.0	3.0	4.1	2.2
Farm-based, whole	5.5	78	3.6	1.7	4.4	0.8	0.6
Farm-based, separated liquor	3.0	89	1.9	0.6	2.5	0.1	0.4
Farm-based, separated fibre	24	25	5.6	4.7	6.0	2.1	1.8

[1]DM = dry matter; [2]RAN = readily available N

The biofertilizers have a higher fertlizer value than the feedstock before digesting



The main digestate treatment methods

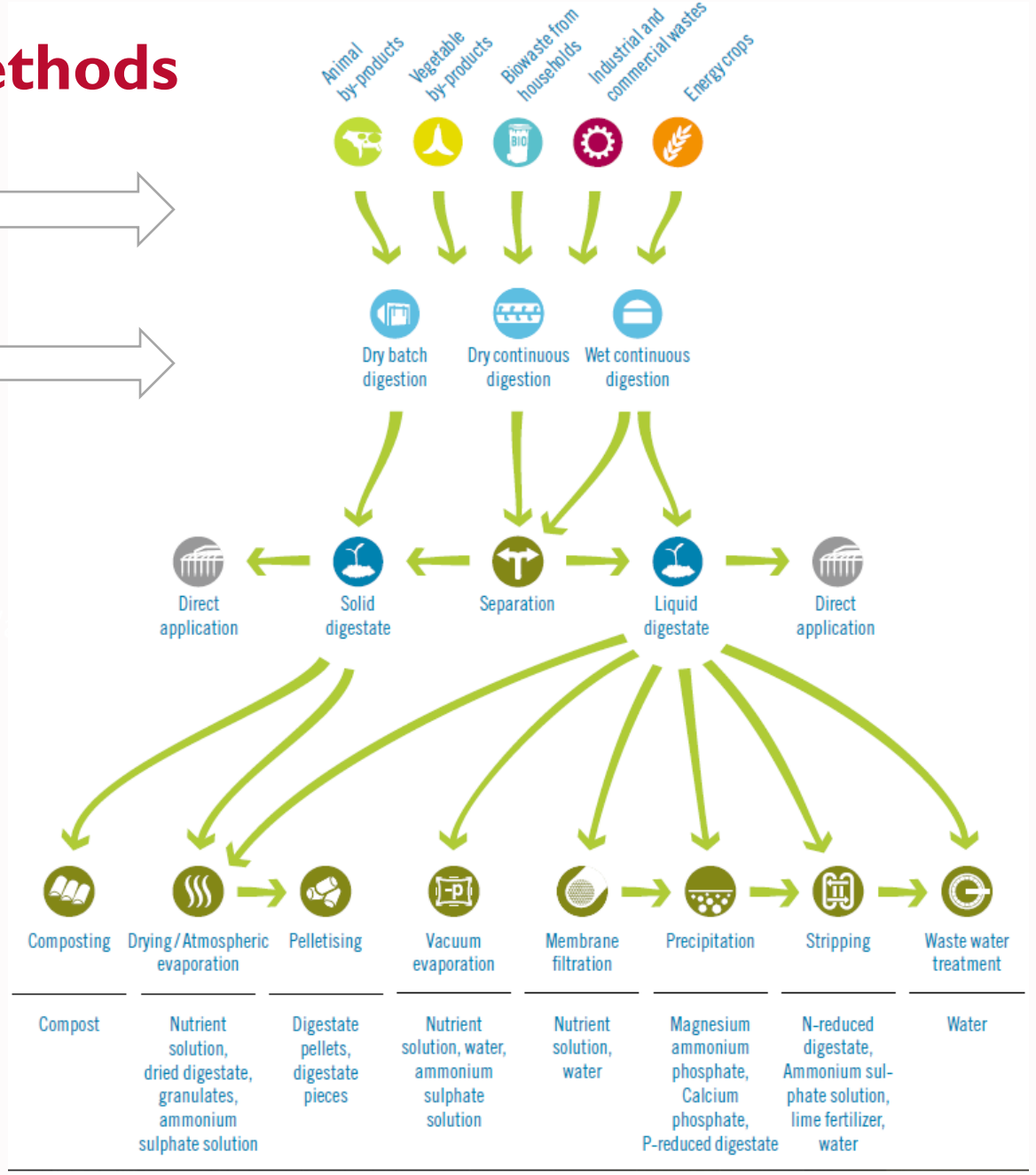
Feedstock, from which digestate is originated

Technology for biogas production

Separation of digestate into liquid and solid fractions

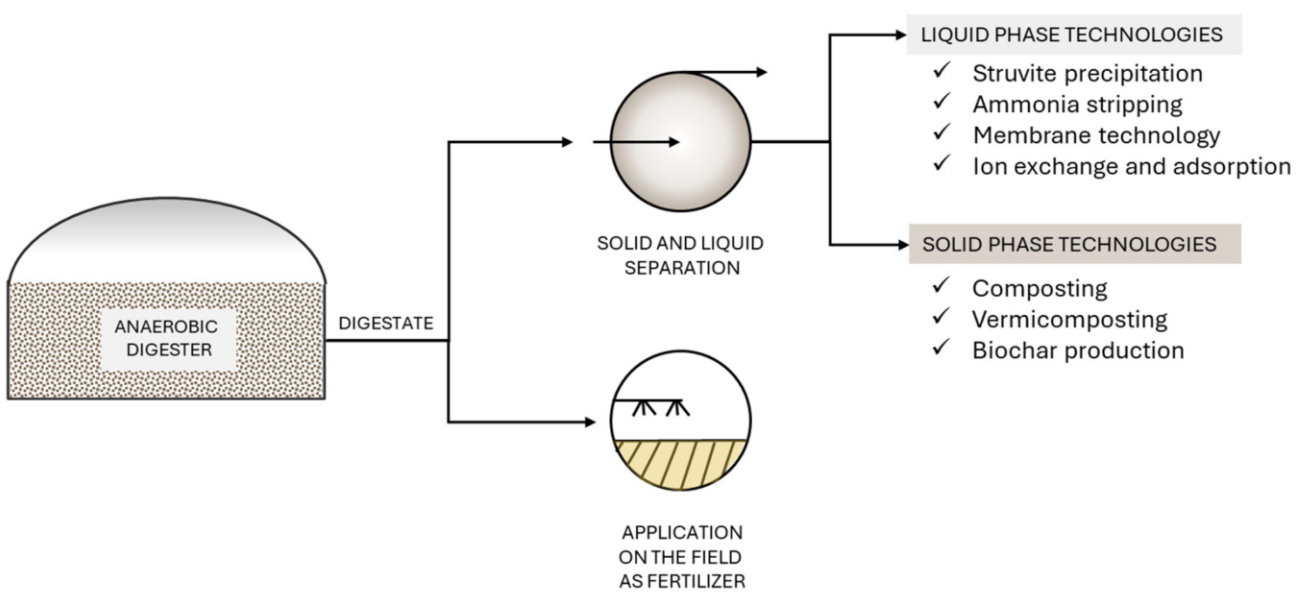
Digestate treatment methods

The digestate derived products

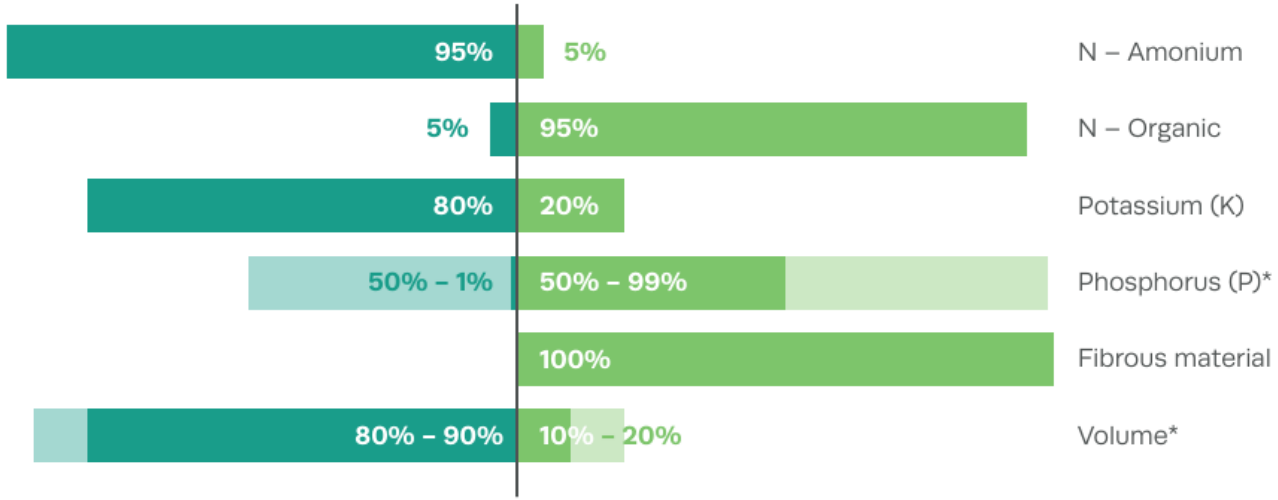


Source: GIZ / German Biogas Association

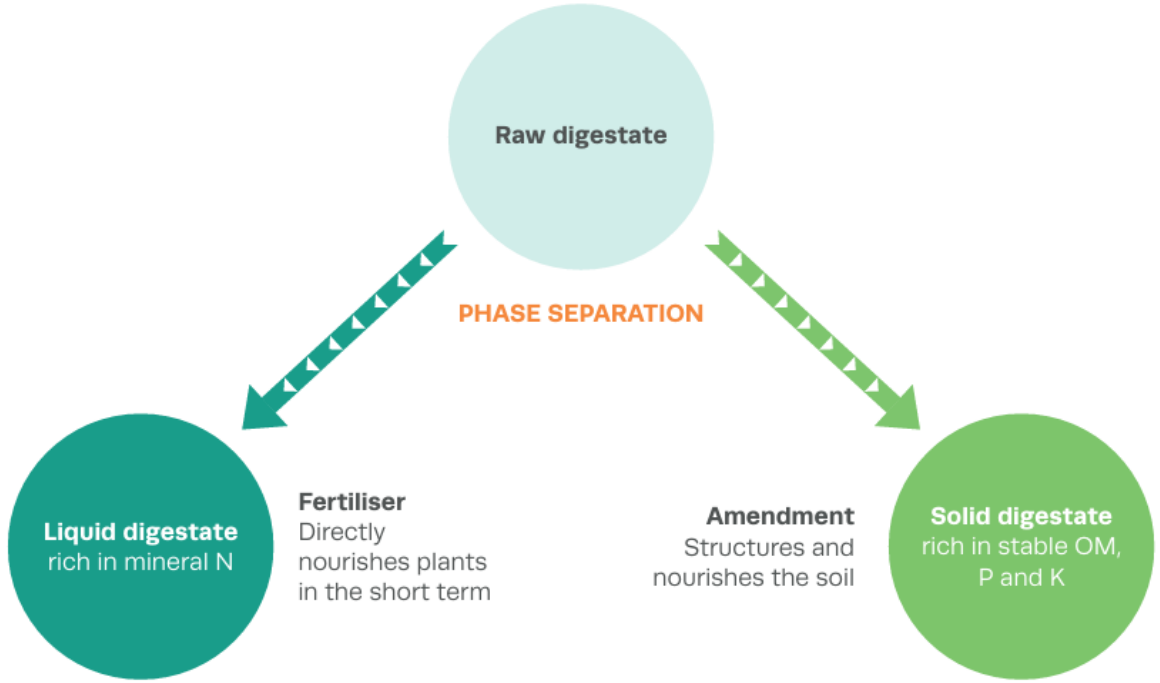
Strategies for recovering valuable products from digestate



Source: *Zielińska & Bułkowska, 2024, https://doi.org/10.3390/en17153705*



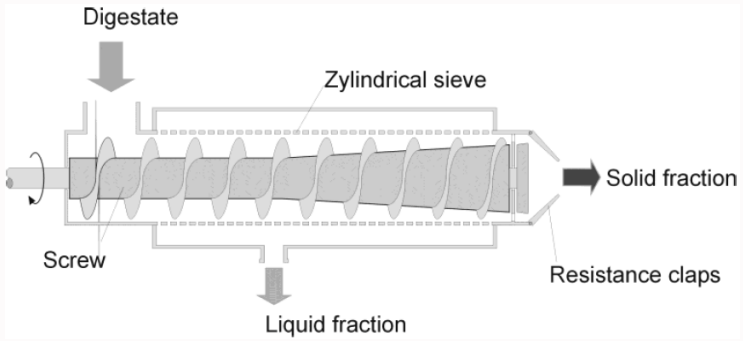
* Depend on the use of coagulants / flocculants for solid phase separation
** Depend on the technique used



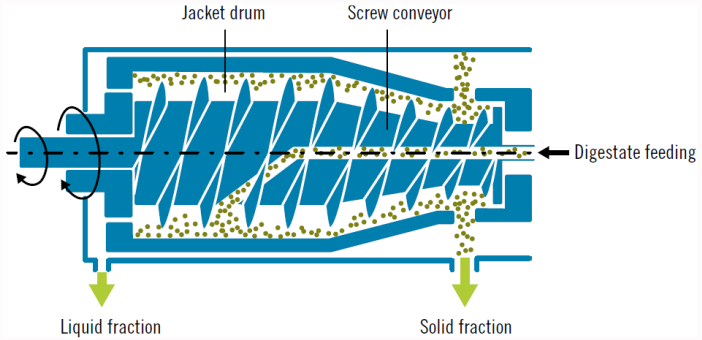
Phase separation of raw digestate and elements distribution between fractions

Source: *EBA. Exploring digestate's contribution to healthy soils, 2024.*

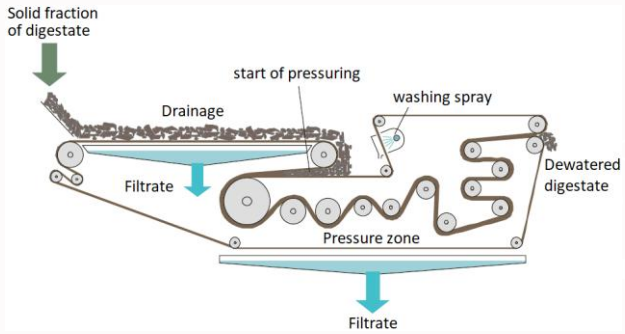
Technologies of digestate separation into solid and liquid fractions



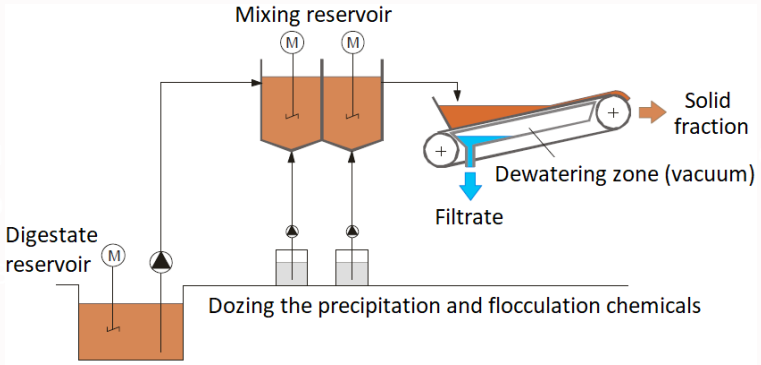
Screw separator



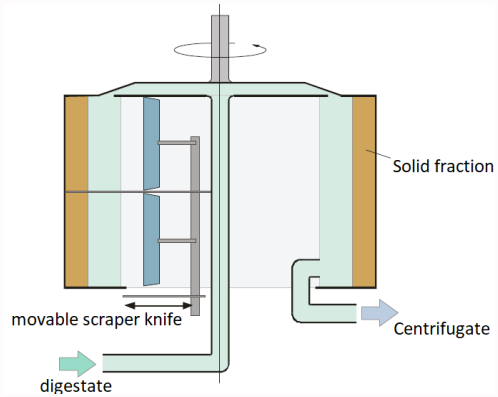
Decanter centrifuge



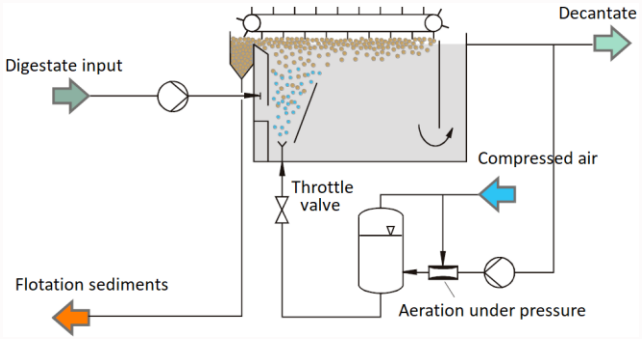
Belt filter press



Vacuum belt filter



Discontinuous centrifuge



Flotation scheme

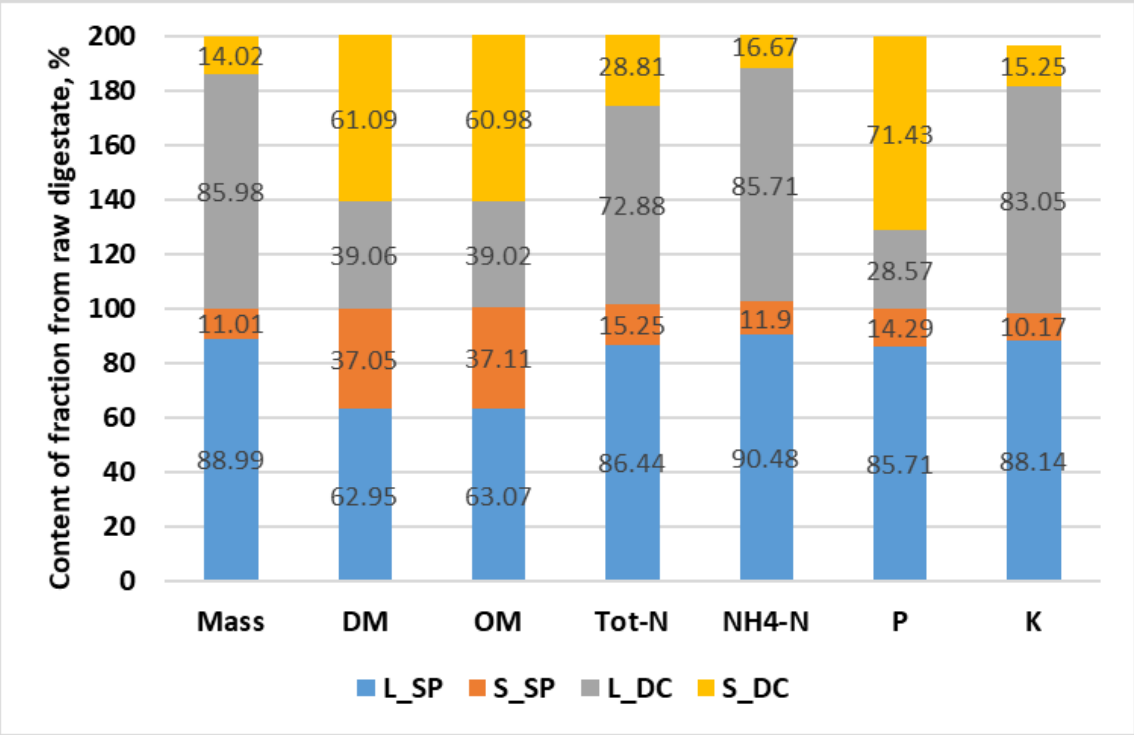
Features of screw separators

- Simple adaptation → often used
- Requires availability of coarse materials for effective operation
- Wear parts: Sieves (depends on ingredients)
- Power consumption ranges from 0.2-0.6 kWh/m³ of input material, depending on the version and performance.

Features of decanter centrifuges

- A high degree of separation, especially when processing digestate with a low dry matter content, with a predominant share of small and colloidal particles
- Suitable for further complete excretion of nutrients
- Usually requires the use of polymers (precipitating/flocculating agents) to improve solids separation
- Power consumption - 2-5 kWh/m³

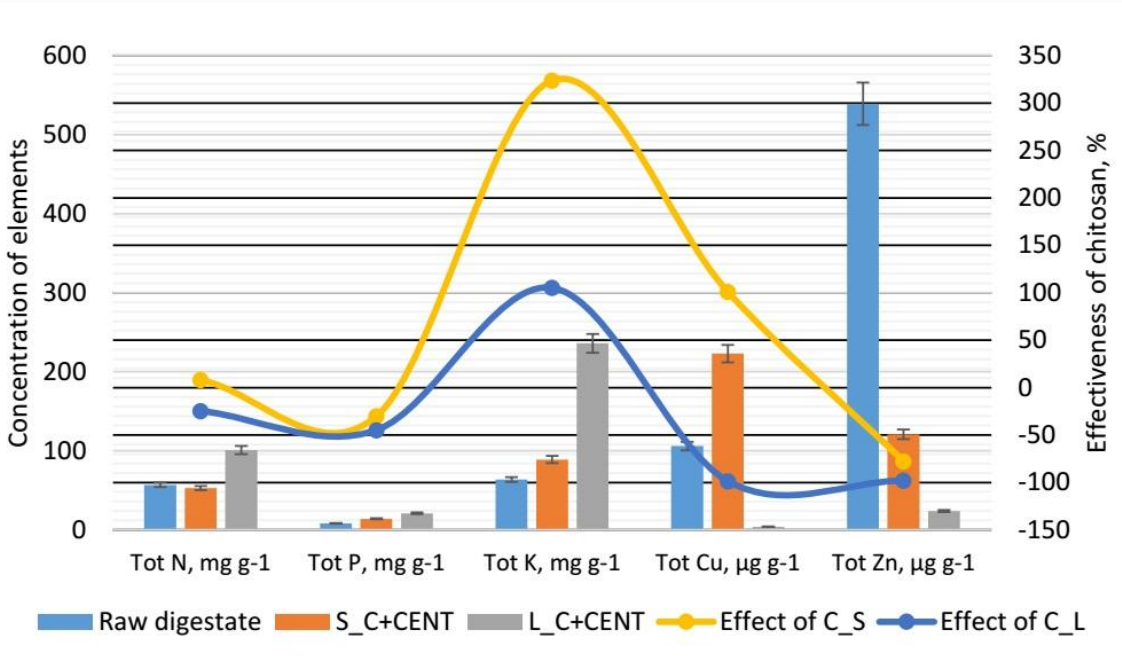
Comparison of the efficiency of a screw press and decanter centrifuge



Comparison of the efficiency of a screw press (SP) and decanter centrifuge (DC) on the nutrient distribution between solid (S) and liquid (L) fractions of the digestate (D), based on Hanserud et al., 2017 (https://doi.org/10.3390/su9040595)

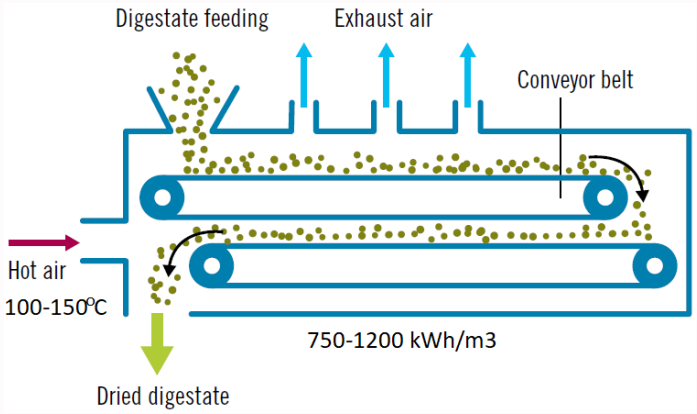
DM – dry matter; OM – organic matter; Tot-N – total nitrogen; NH_4-N – ammonium nitrogen

Nutrients and HM distribution between solid (S) and liquid (L) fractions after centrifugation with chitosan addition (C+CENT), and effectiveness of chitosan addition before centrifugation (C), based on Popovic et al., 2017 (https://doi.org/10.3390/su9122302)

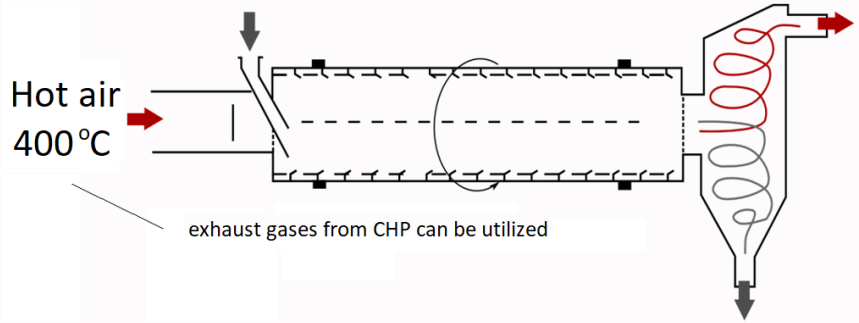


Dewatering technologies for digestate

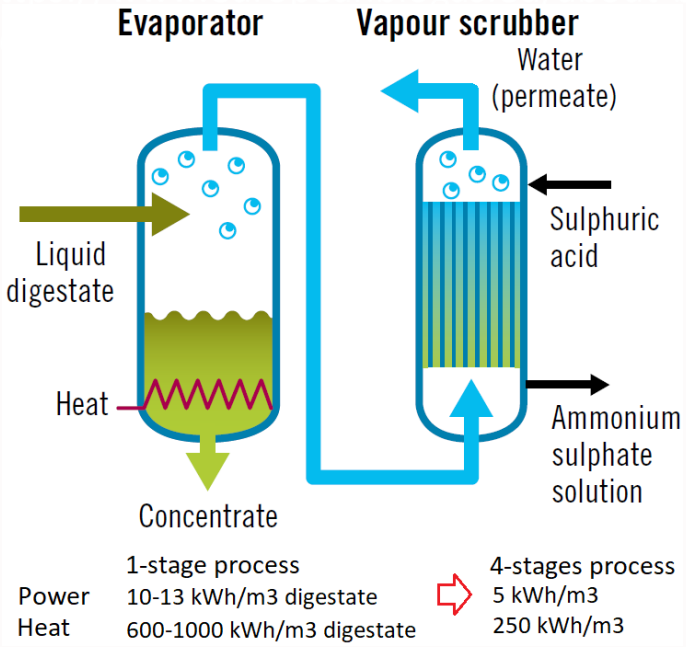
Belt dryer



Drum dryer



Vacuum evaporator

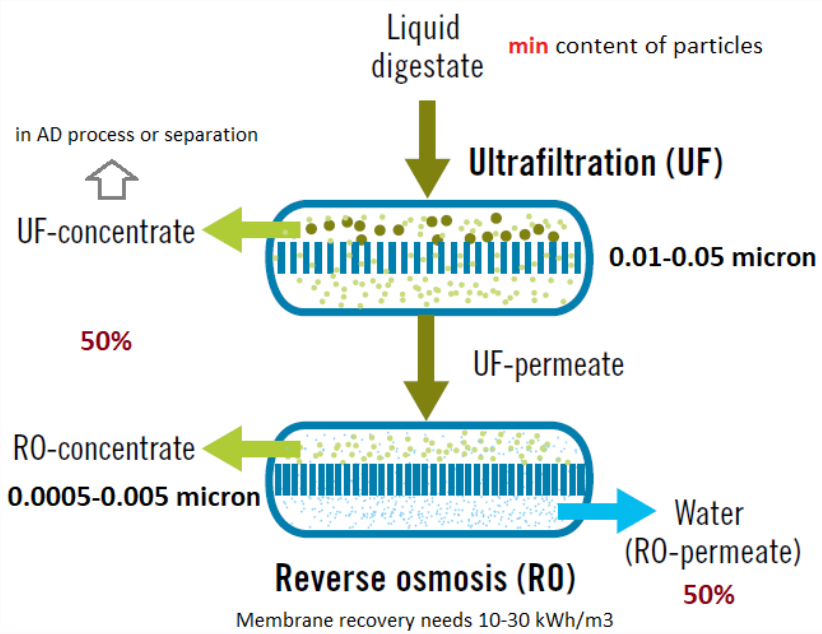


Greenhouse (sun) dryer

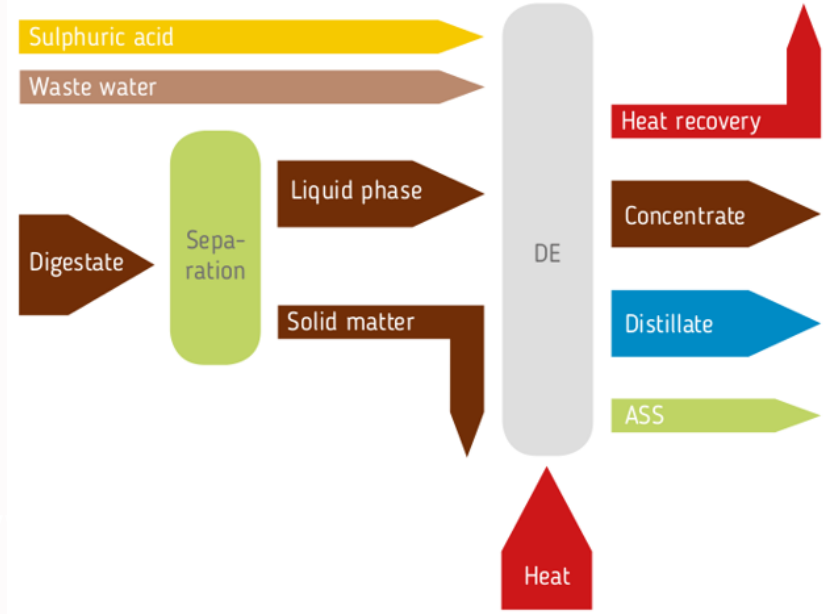
- Warm air with a temperature of about 40°C is supplied by fans over the surface of the digestate
- Drying is also ensured by the penetration of solar radiation into the greenhouse

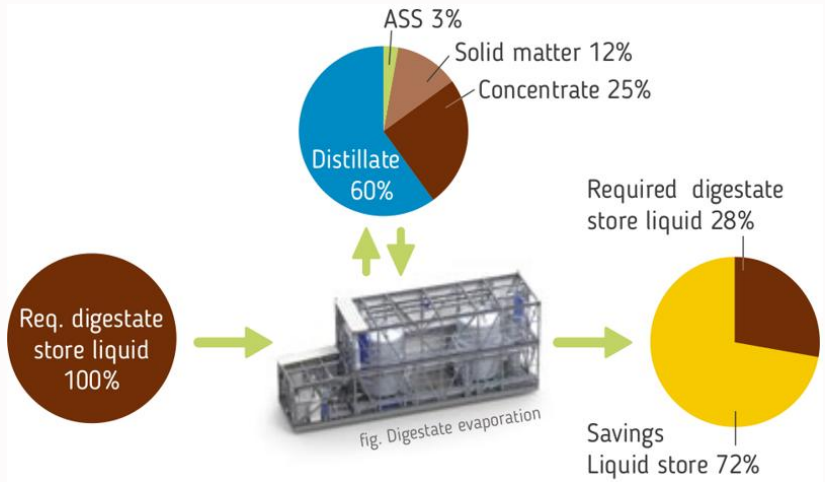
Concentration technologies

Membrane filtration

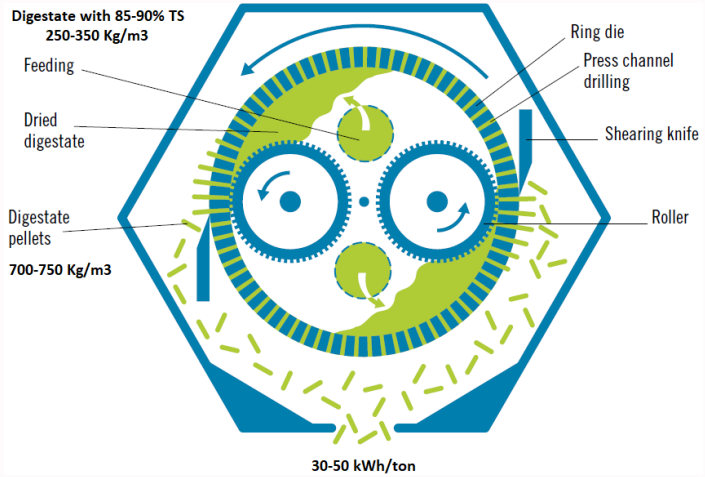


Evaporation technology Vapogant

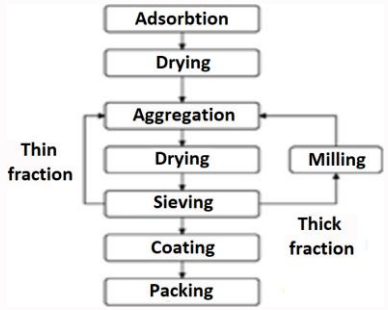




Solid fraction pelletizing



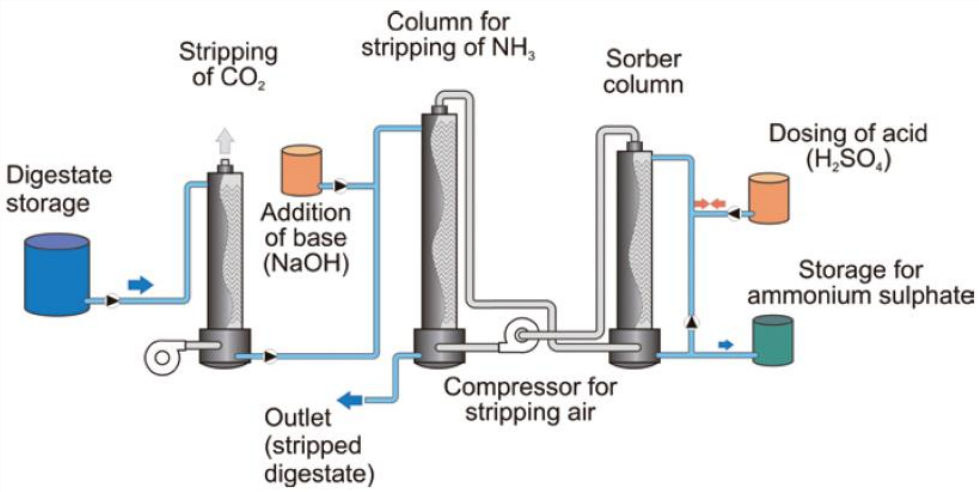
Pellets from liguid fraction



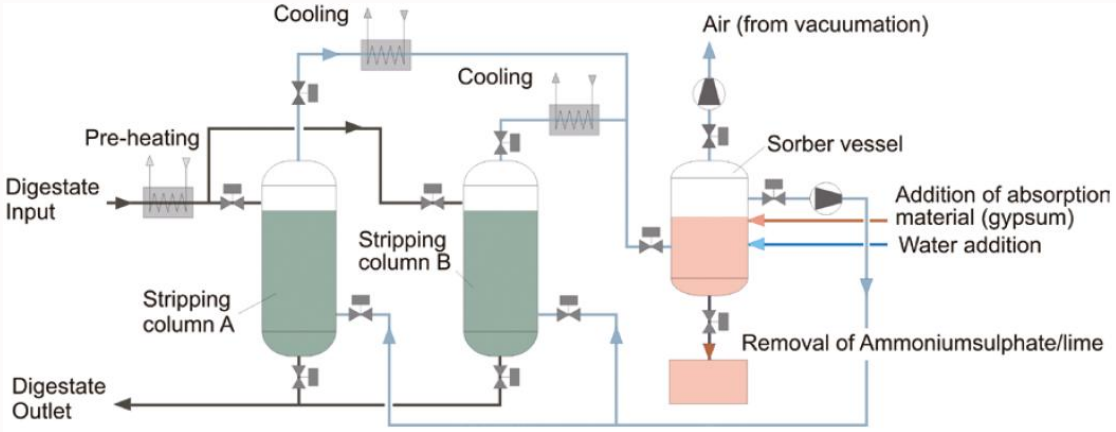
Excretion technologies for individual substances

Ammonia stripping

Ammonia stripping, including CO_2 removal and ammonia regeneration with sulfuric acid

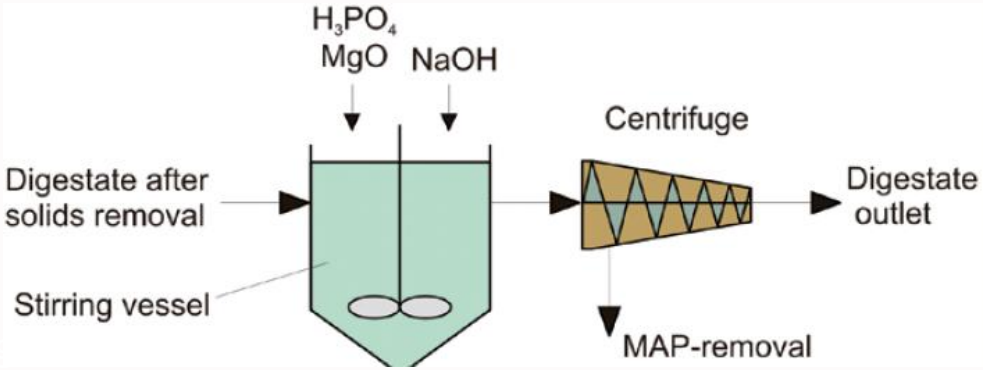


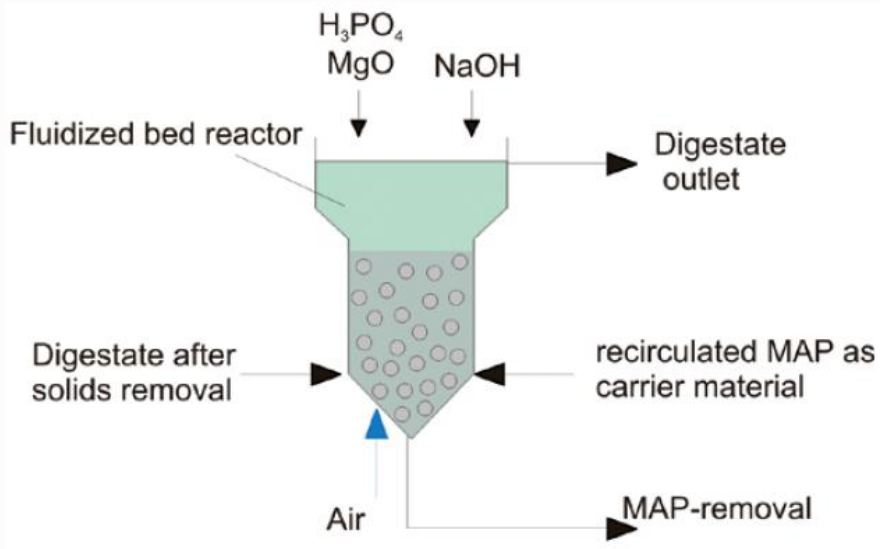
In-vessel stripping process without stripping columns



Struvite precipitation

$$Mg^{2+} + NH^{4+} + HPO_4^{2-} + OH^- + 5\ H_2O \rightarrow MgNH_4PO_4 \cdot 6\ H_2O$$



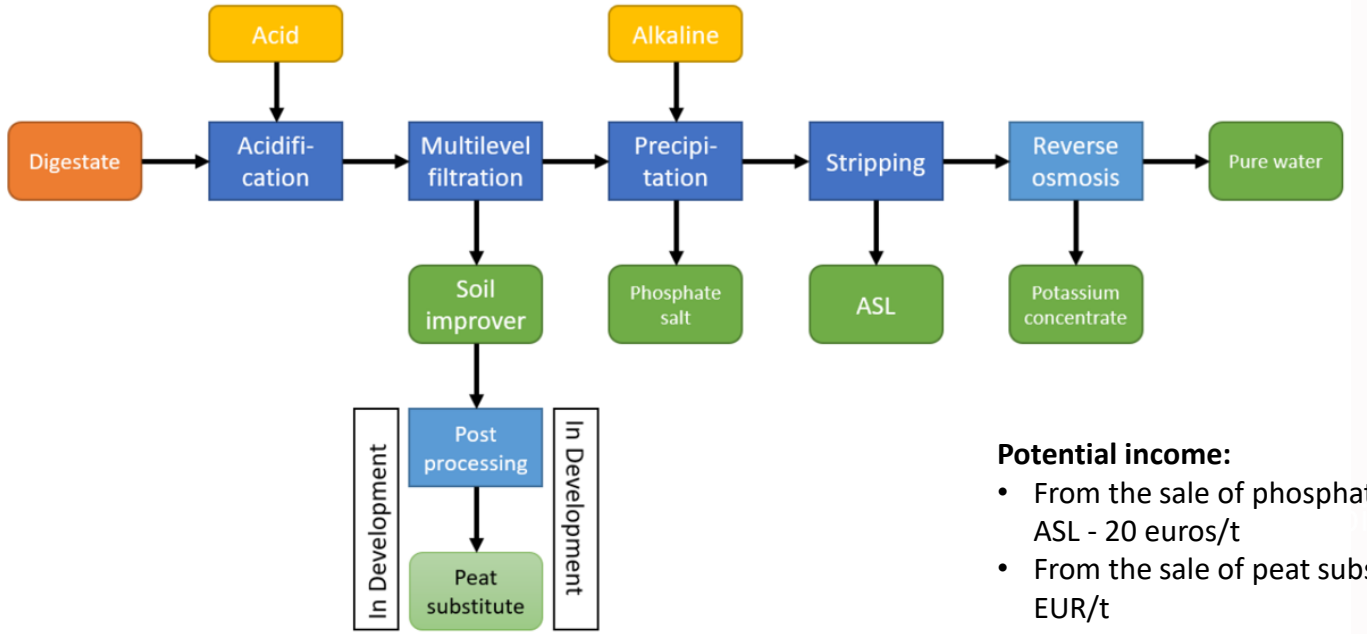


The main derived products from digestate

Digestate derived product	DM, %	Bulk density, Kg/m³	Nutrients	Methods of processing	Energy consumption	Materials consumption	Application and market niches
Solid fraction of digestate **(SFD)**	20-40		Complex N – 25-35% of RD P – 55-65% of RD K – 20-30% of RD C – 60-70% of RD	Solid-liquid separation of RD	0.2-0.6 – SP 2-5 – DC 1.2-5 - BP	No (for fiber-rich RD) Precipitation/ flocculation agents (for fine separation)	Complex organic fertilizer; Soil improver; Component for co-composting; Component for soil reclamation; Component for DSFD and DP production
Liquid fraction of digestate **(LFD)**	1-8	Appr. 1000-1030	Complex N – 65-75% of RD P – 35-45% of RD K – 70-80% of RD C – 60-70% of RD	Solid-liquid separation of RD	0.2-0.6 – SP 2-5 – DC 1.2-5 - BP	No	Fast-released complex organic fertilizer at nearby agriculture lands; Component for DDP production
Dried solid fraction of digestate **(DSFD)**	> 90	250-350	Complex (as in SFD (NH_3 reduced via heating)	Drying of SFD	750-1200 kWh_{therm}/m^3 H_2O	No	Slow-released organic fertilizer; Soil improver; Component for DP production
Digestate pellets **(DP)**	> 90	700-750	Complex (as in DSFD)	Pelletizing of DSFD	30-50 kWh_{el}/t	No	Slow-released concentrated organic fertilizer; Energy production
Ammonium sulphate **(AS)**		Solution	$(NH_4)_2SO_4$	Air/Steam stripping of LFD with H_2SO_4 regeneration	5-10 kWh_{el} + 45-100 kWh_{th} per 1 m³	H_2SO_4	Substitution of artificial ammonium sulphate Chemical industry
N-reduced digestate **(N-D)**	1-8	Appr. 1000-1030	Complex (NH_3 reduced)	Air/Steam stripping of LFD with H_2SO_4 regeneration	Produced with AS	No	Recycle to AD process; N-reduced complex organic fertilizer
Ammonia water **(AW)**		Solution	$NH_3 \cdot H_2O$ 25…35% of NH_3	Steam stripping of LFD	5-10 kWh_{el} + 45-100 kWh_{th} per 1 m³	Water	Substitution of artificial ammonia water Chemical industry
Magnesium ammonia phosphate **(struvite) (MAP)**		Crystal stone	$MgNH_4PO_4 \cdot 6H_2O$	Precipitation of permeate after filtration of LFD	10-15 kWh_{el}/m^3	H_3PO_4, MgO, NaOH	Substitution of N, P fertilizers Chemical industry
N-reached MAP **(N+MAP)**			MAP + AS	Enrichment with AS		$(NH_4)_2SO_4$	Substitution of N, P fertilizers
RO-concentrate **(RO-C)**			Complex	Micro-, ultra-, nano-filtration, RO	10-30 kWh_{el}/m^3	Precipitation/ flocculation agents	Fast-released concentrated organic fertilizer
Granular fertilizer **(GF)**			Complex	Adsorbtion in LFD		Adsorbers	Slow-released concentrated organic fertilizer

Complex technologies of digestate treatment

NuTriSep technology



Potential income:

- From the sale of phosphate salt and ASL - 20 euros/t
- From the sale of peat substitute - 4 EUR/t

Source: Fabian Geltz, Geltz Umwettechnik GmbH, 2021

Cost item	Cost, EUR/year
Supplies	360000
Amortization (10 years)	250000
Profit (2%)	25000
Personnel (+ 1 person)	60000
Energy (CHP)	125000
Maintenance	120000
Insurance	20000
TOTAL	960000
Cost per 1 ton (70 ths, ton per year)	**13,71 EUR**
Additionally for potassium concentrate + peat substitute, EUR/t	≈ (+5 EUR)

Techno-economic feasibility of nutrients recovery from anaerobic digestate in the agricultural sector

Technology	Efficiency	Cost / Expenses	Full-Scale Examples
Ammonia Stripping	Nitrogen recovery yield of 80–90%	3–6 €/m³ digestate	• AMFER® system (Netherlands): 50% N removal, produces ammonium sulfate/nitrate • Biogas Bree (Belgium): 600 t/year ammonium sulfate • Detricon (Belgium): 18% N recovery as ammonium nitrate
Struvite Precipitation	Phosphorus removal yield of 80–90%	270–2,000 €/t phosphorus removed	• AirPrex™ (Germany): 90% P precipitation with sewage sludge • Ostara's Pearl® (Spain): 2 t/day struvite granules • REVAWASTE® (Spain): 95.4% nutrient recovery
Pressure-Driven Membrane Filtration	Up to 99% recovery of N and P	4–12 €/m³ digestate	• Lastrup (Germany): 99% N and P recovery • Beltrum (Netherlands): 98% P recovery, 48% NH_4-N recovery • Biogas Wipptal (Italy): solid fertilizers via reverse osmosis
Hydrothermal Carbonization (HTC)	P recovery up to 91%	157 €/t digestate	• Mezzocorona (Italy): industrial-scale HTC with high P recovery • Terranova (China): 14,000 t/year sewage sludge
Ion Exchange and Adsorption	Up to 89% N and 80% P recovery	–	• LayneRT resin (UK): demonstrative scale, 51% P recovery
Evaporation	50% volume reduction	High energy demand (300–350 kWh/t water evaporated)	• Vacuum evaporation systems (Italy)
Membrane Contactors	Ammonia removal yield of 85–98%	–	• Pilot plants (Switzerland and Denmark)

Source: Rizzioli et., 2023, https://doi.org/10.1016/j.seppur.2022.122690

Application techniques for liquid fraction of digestate

Hose application:
precise fertilizer application, approximately 41% lower NH_3 loss

Spreading liquid organic fertilizers with trailed hose equipment. (Photo: Mårten Svensson)

Hose application with simultaneous plowing into the soil

Spreading the fertilizer directly under the soil surface. (Photo Emelie Andersson)

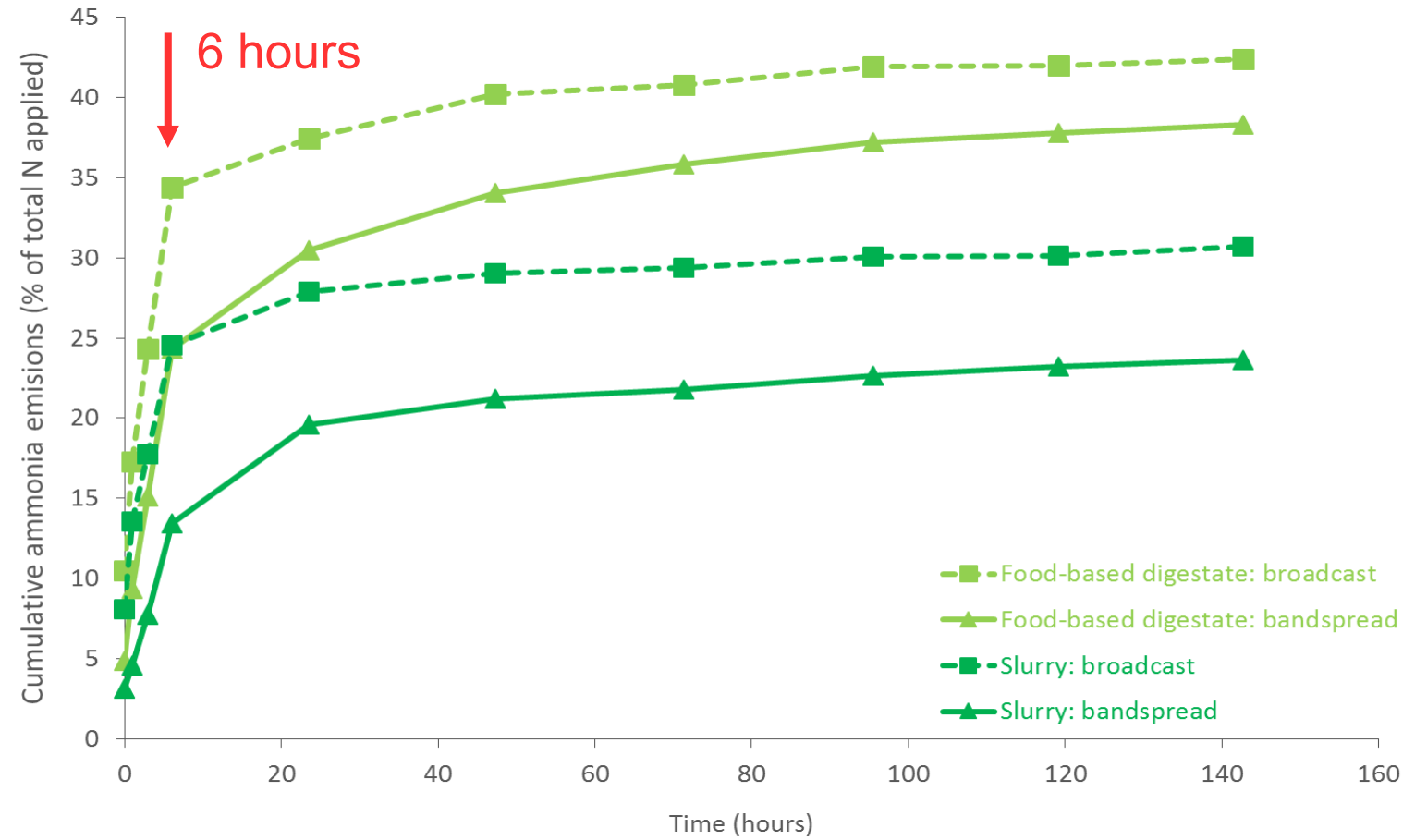
Flat application:
intensive odor and ammonia loss, sensitive to wind

Trailing shoe injection

Source: Gödselmedelsproduktion i Sverige, Jordbruksverket, 2023

Nitrogen losses when applying digestate to the soil

NH_3 losses into the atmosphere after application to the soil

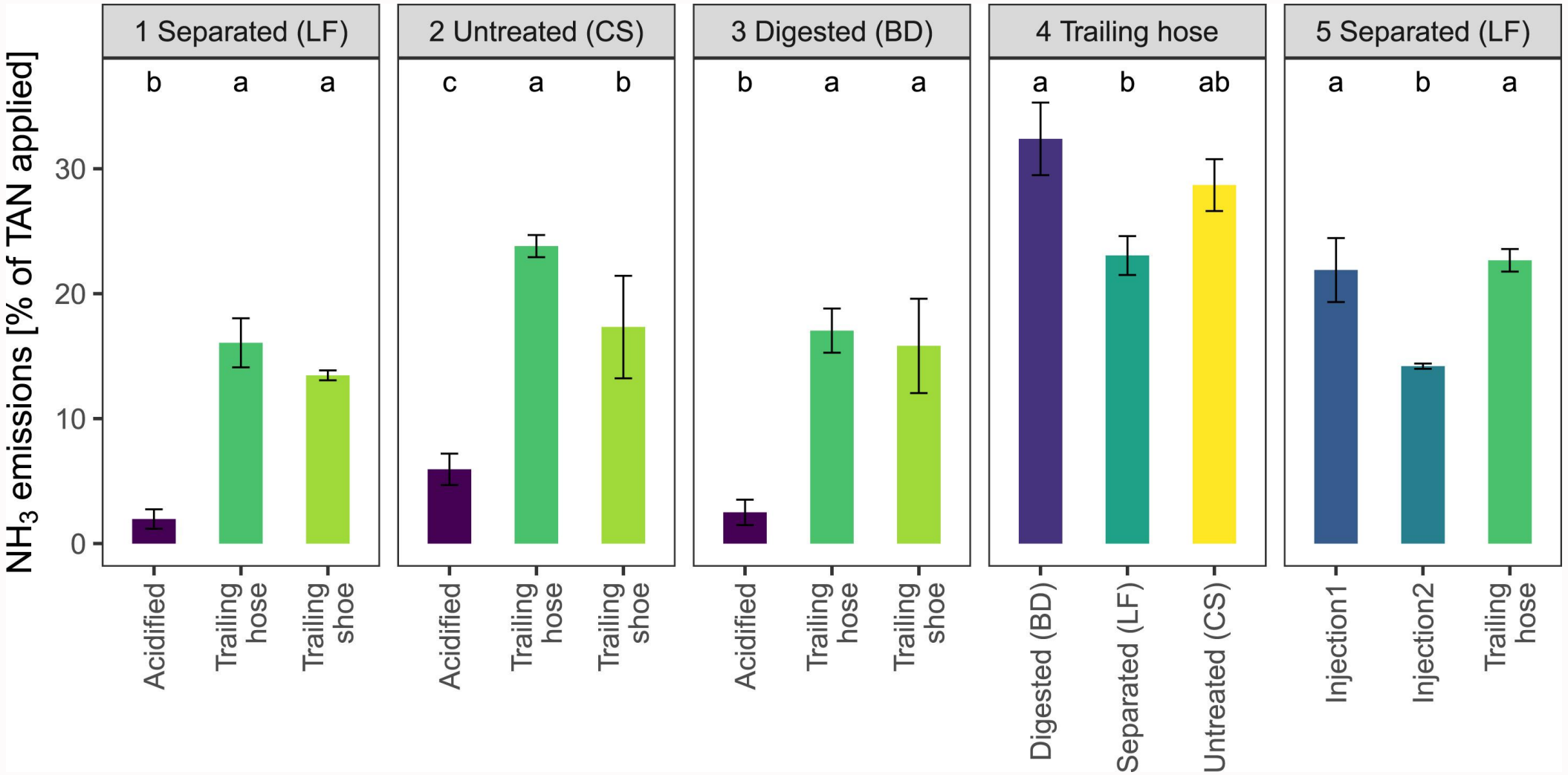


Source: Bryan Lewens, UK 2017

Ammonia losses can be significantly reduced by:

- A hose or other equipment is used for accurate fertilizer application
- The digestate is plowed into the soil as quickly as possible

Ammonia emissions from untreated, separated and digested cattle slurry – Effects of slurry type and application strategy on a Swedish clay soil



Cumulative ammonia emissions 70 h after slurry application (n = 3)

Source: Andersson et al., 2023, https://doi.org/10.1016/j.biosystemseng.2023.01.012

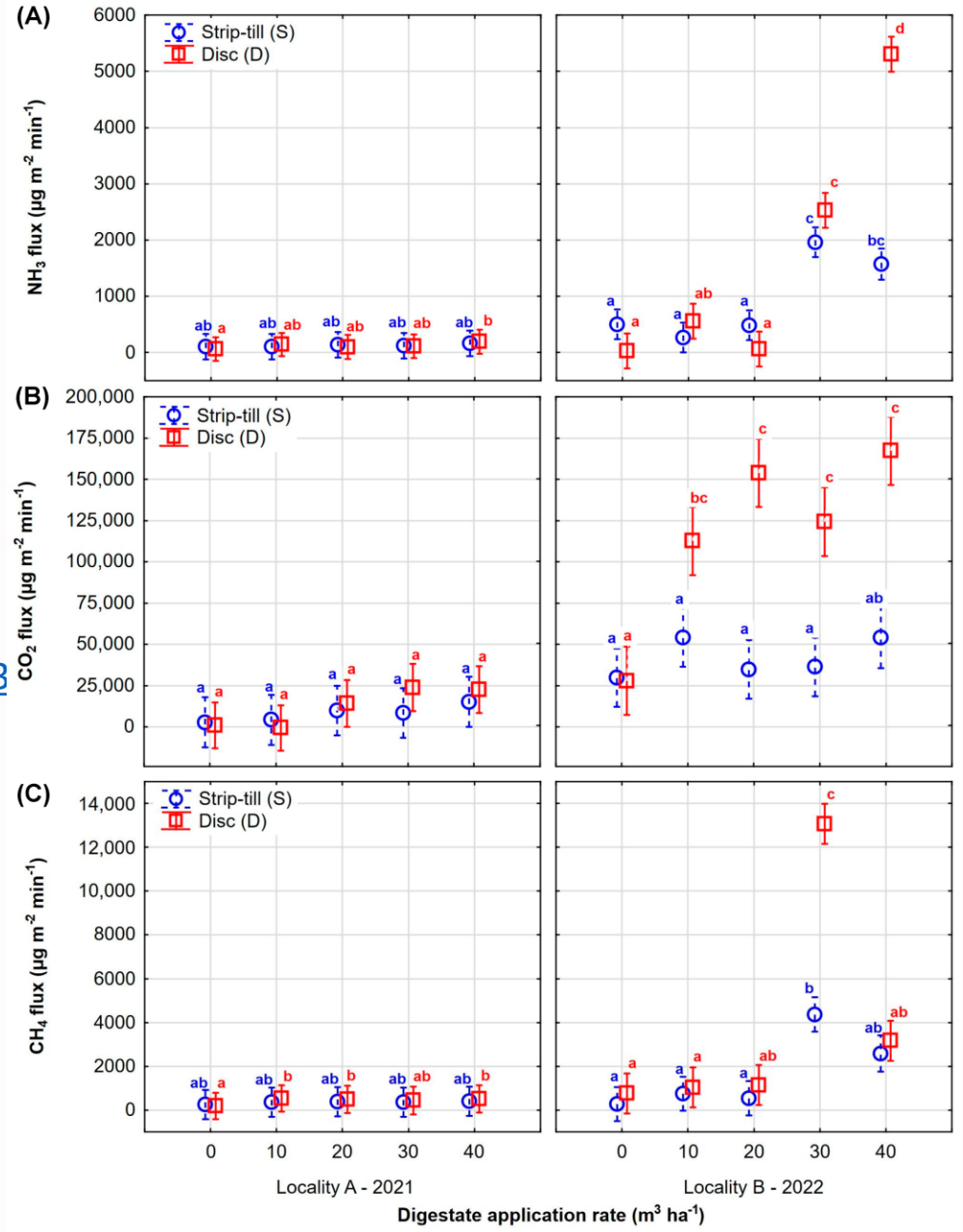
Digestate Application Methods and Rates with Regard to Greenhouse Gas Emission

(A)

(B)

Digestate application units used:
(A) strip-till application unit,
(B) disc application unit

Source: Kobra et al., 2024,
https://doi.org/10.3390/agronomy14020336



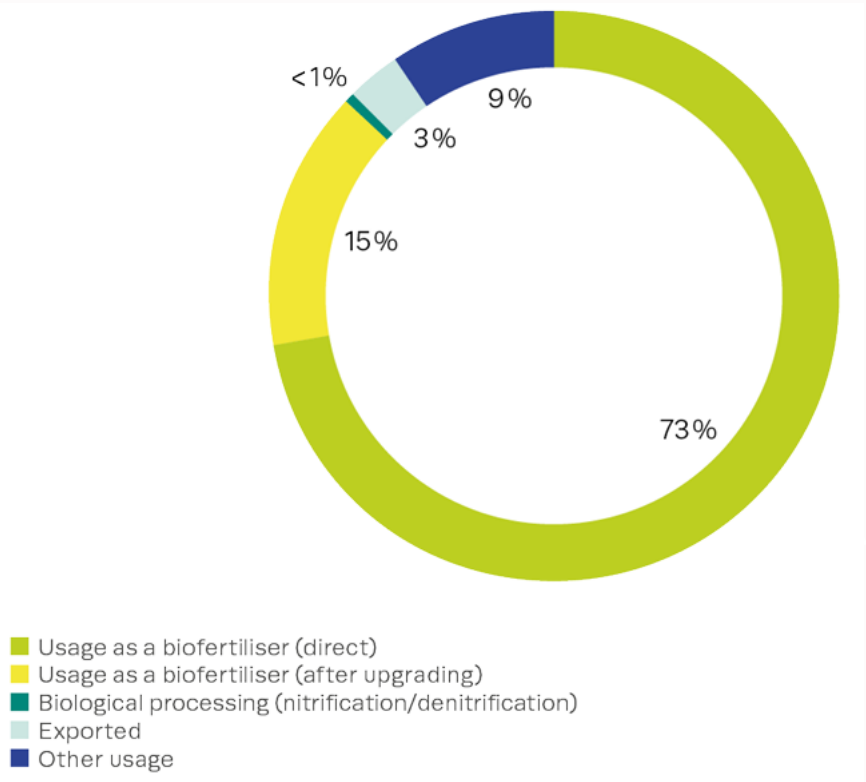
Flux values of measured gases, (A) ammonia, (B) carbon dioxide, and (C) methane

Application techniques for solid fraction of digestate

Spreaders used in the vineyard: broadcast spreading on the left and localised on the right

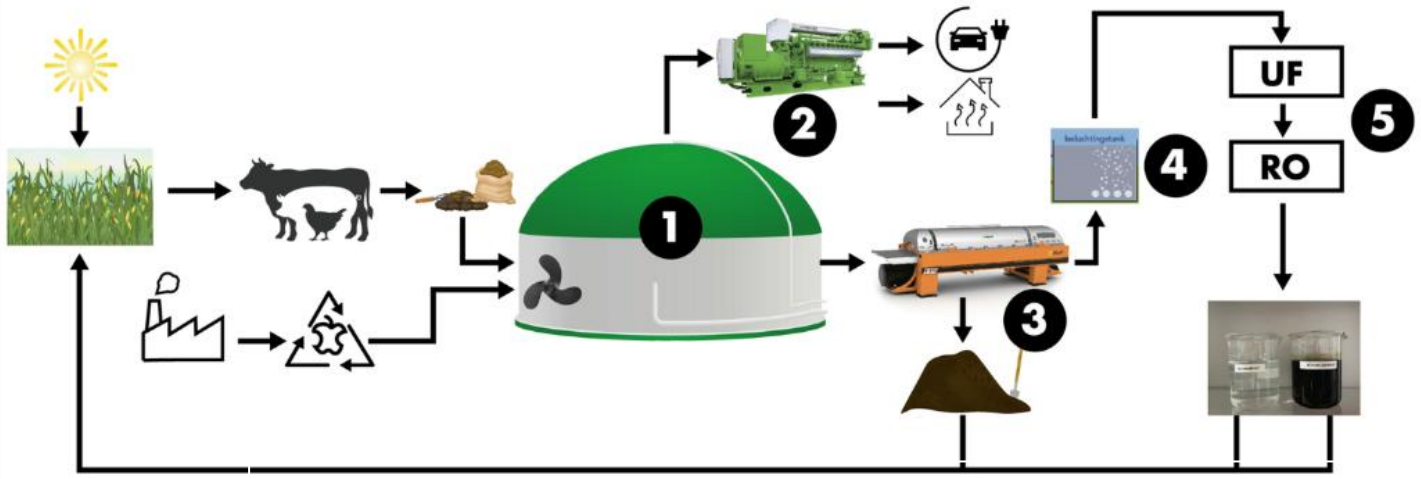
Source: Giuseppe et al., 2020, DOI: 10.1016/j.heliyon.2020.e04257

Marketing strategies and case studies



Overview of selected digestate valorisation routes

Source: *EBA. Exploring digestate's contribution to healthy soils, 2024.*



Source: *https://www.guilliamsgroup.be/green-power*

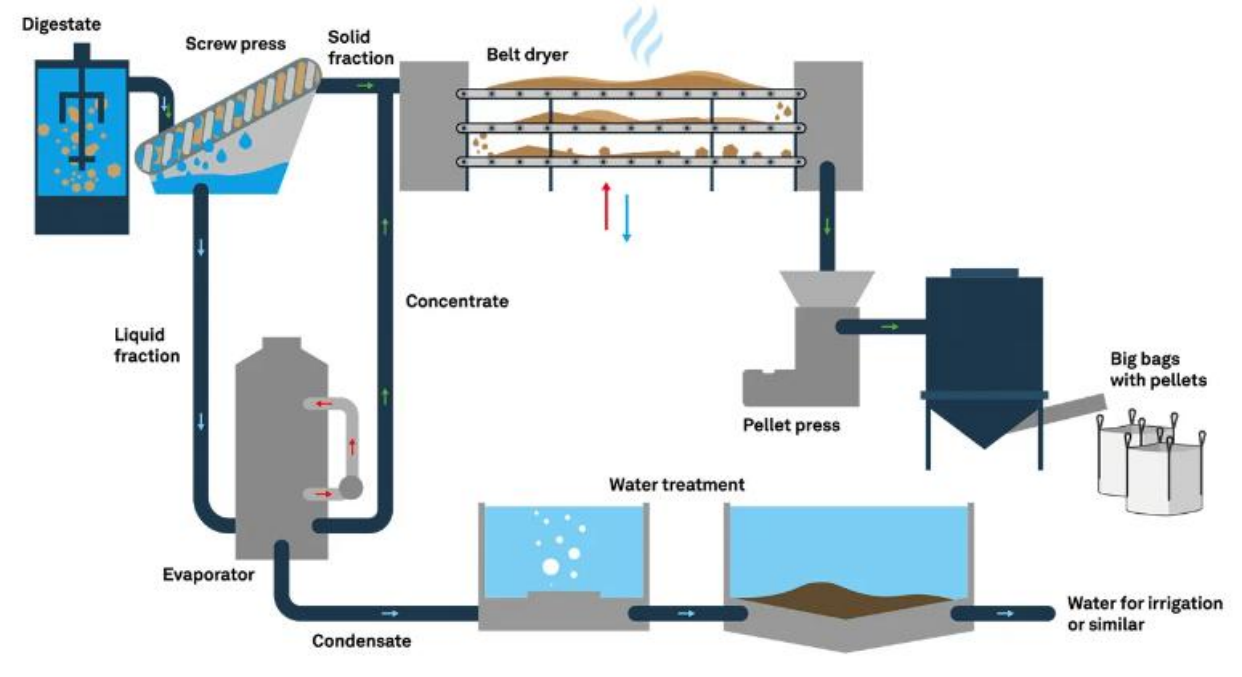
Key facts:

- **Plant size:** 3 MW electric capacity
- **Location:** Boutersem, Belgium
- **Digestate products:**
  - → 200 litres/day clean water
  - → Solid fraction organic fertiliser
  - → Soil improver
- **Digestate upgrading technology:** digestate separation, nitrification/denitrification, ultra-filtration, reverse osmosis.
- **Start of operation:** 2008

Guilliams Green Power plant, Belgium

Source: *EBA. Exploring digestate's contribution to healthy soils, 2024.*

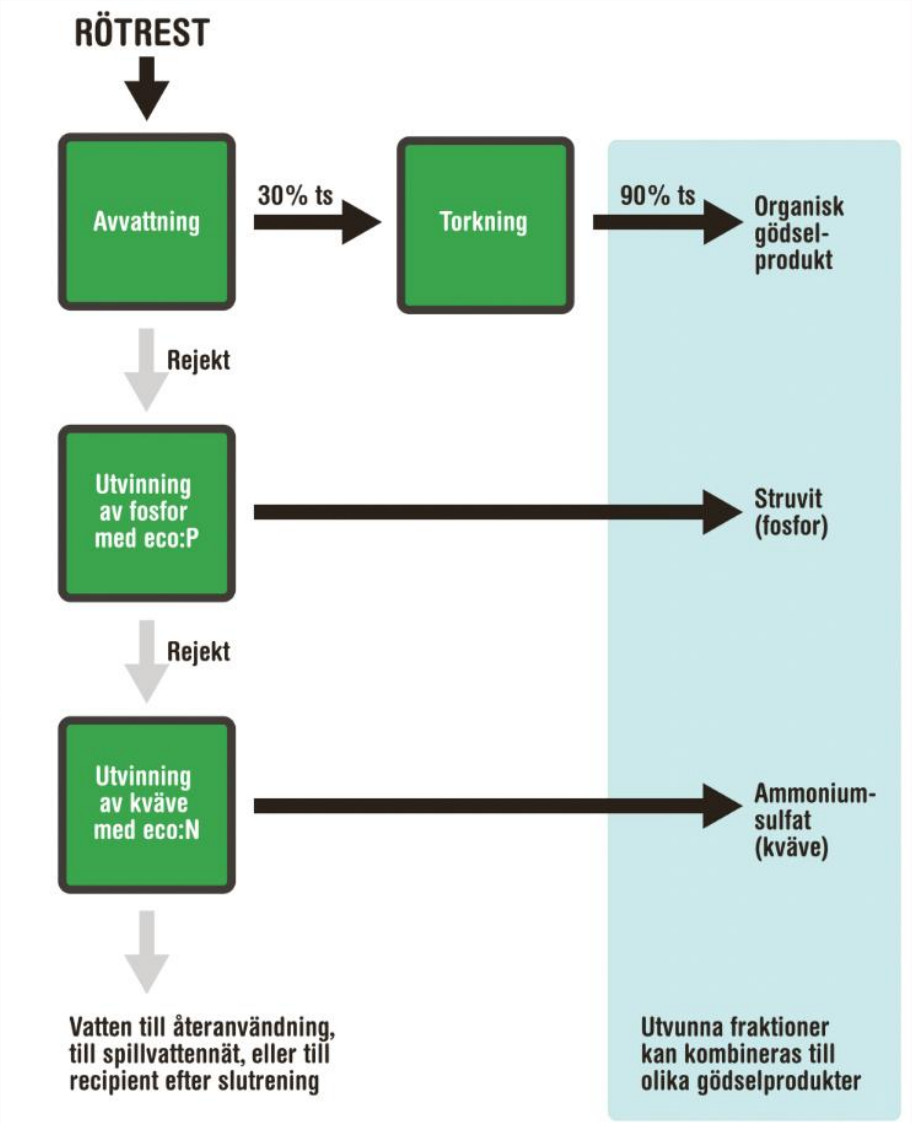
Digestate valorization in Sweden: case studies



Technological scheme Purac ReNu™ - Recirculated Nutrients

- The capacity of the plant is 30,000 tons of digestate per year with a TS content of approximately 3.5%
- 1,800 tons of biopellets with the composition NPK 7-1-3 as well as magnesium, sulfur, calcium and micronutrients

Source: https://purac.se/erbjudande/biogas/



Flow chart of the EcoBalance technology

2,000 tons/year of finished pelletized NPK product with an approximate composition of 9:1:1 (%)

Source: https://ekobalans.se/en/digestate-processing/

Biofertilizer products development in Sweden: new markets and better adapted to farmers needs

EKOBALANS

- for gardens
- biofertilizers for organic farmers

biototal

Biond

Renahav

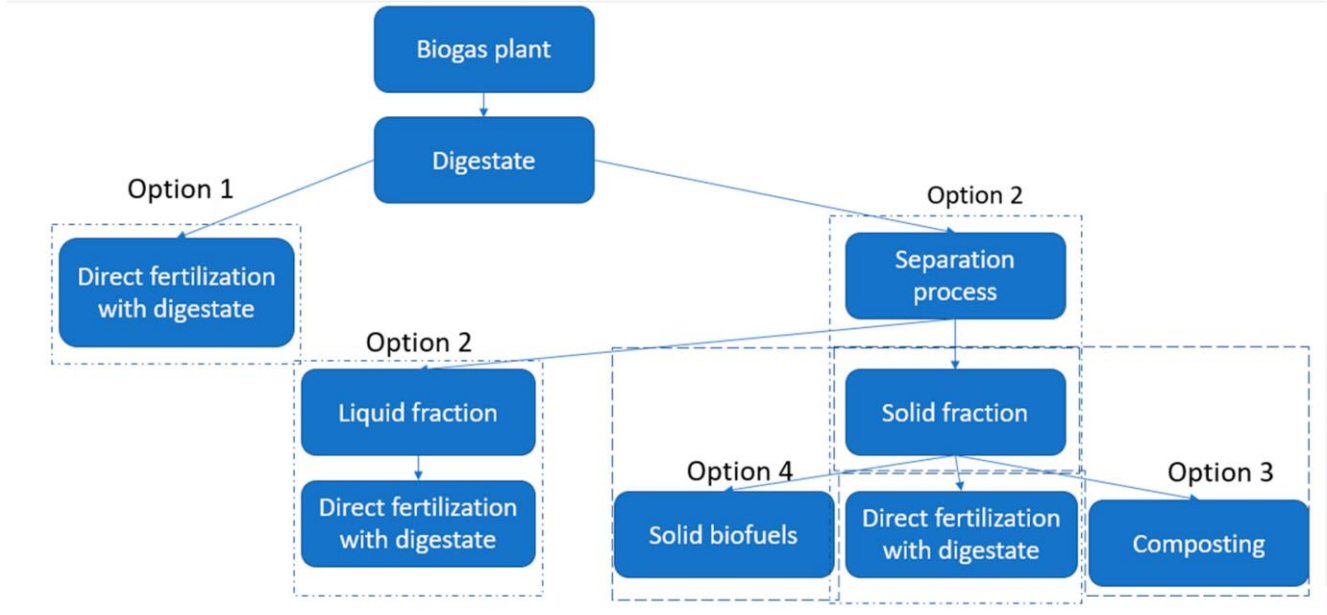
MORE BIOGAS

Development projects (SLU, Uppsala; RI.se)

St1 Biokraft

***Biomull*:** Dewatered to 25-27%
***Biospets*:** Pumpable concentrate with 16-18% TS
Liquid manurel: Slurry with 3-4% TS

Economic and Energy Efficiency Analysis of the Biogas Plant Digestate Management Methods (Polish case-study)



Flow chart of the digestate management options
Source: Nowak et., 2024, https://doi.org/10.3390/en17123021

Parameters of the digestate (formed mainly from manure and corn silage) and its fractions
Source: Nowak et., 2024, https://doi.org/10.3390/en17123021

Name	Unit	Raw Digestate	Solid Fraction	Liquid Fraction
Dry mass	[%]	6.1	29.67	3.9
Organic dry matter	[% D.M.]	71.2	91.50	64.4
pH	[-]	7.69	8.49	7.96
Total nitrogen	[N kg·Mg_{FM}^{-1}]	5.8	4.9	3.7
Mass	[Mg_{FM}·$year^{-1}$]	71,500	21,450	50,050

Summary of calculations for selected methods of digestate management
Source: Nowak et., 2024, https://doi.org/10.3390/en17123021

Name	Direct Application of Raw Digestate	Separation of the Digestate and Application of its Fraction	Composting the Solid Fraction of Digestate	Production of Solid Biofuels (Pellets)
Cost per unit	1.98 EUR·Mg^{-1}	0.44 EUR·Mg^{-1}	1.29 EUR·Mg^{-1}	11.57 EUR·Mg^{-1}
Total cost	141,670 EUR	173,130 EUR	200,801 EUR	421,307 EUR
Income	418,705 EUR	432,218 EUR	512,733 EUR	756,233 EUR
Profits	277,035 EUR	259,088 EUR	311,932 EUR	334,926 EUR

A case study of the use of digestate in Ukraine by MHP Eco Energy (1)

Digestate from MHP`s biogas plants as highly efficient organic fertilizer

Liquid fraction, in 1 m3:

Total Nitrogen - 6.6 Kg
Total Phosphorus - 1.9 Kg
Total Potassium - 6.2 Kg
pH - 7.7 - 9.1

Solid fraction, in 1 ton:

Total Nitrogen - 6.8 Kg
Total Phosphorus - 3.1 Kg
Total Potassium - 2.7 Kg
pH - 7.7 - 9.3

- The composition of organic matter is well balanced: the mass fraction of humic acids is - 0.21% (liquid fraction) and 1.87% (solid fraction); the mass fraction of fulvic acids is 0.07 (liquid fraction) and 0.94% (solid fraction).
- Medical and toxicological indicators are normal: there is no excess of the maximum permissible concentrations.
- Optimal trace element composition: manganese - 21.03 and 47.65 mg/Kg; zinc – 8.18 and 12.49 mg/Kg; copper – 14.07 and 34.47 mg/Kg; cobalt – 7.21 and 18.12 mg/Kg; sulfur in liquid - 0.27 and 1.56%.

Source: Olexander Dombrovsky, MHP Eco Energy, 2020

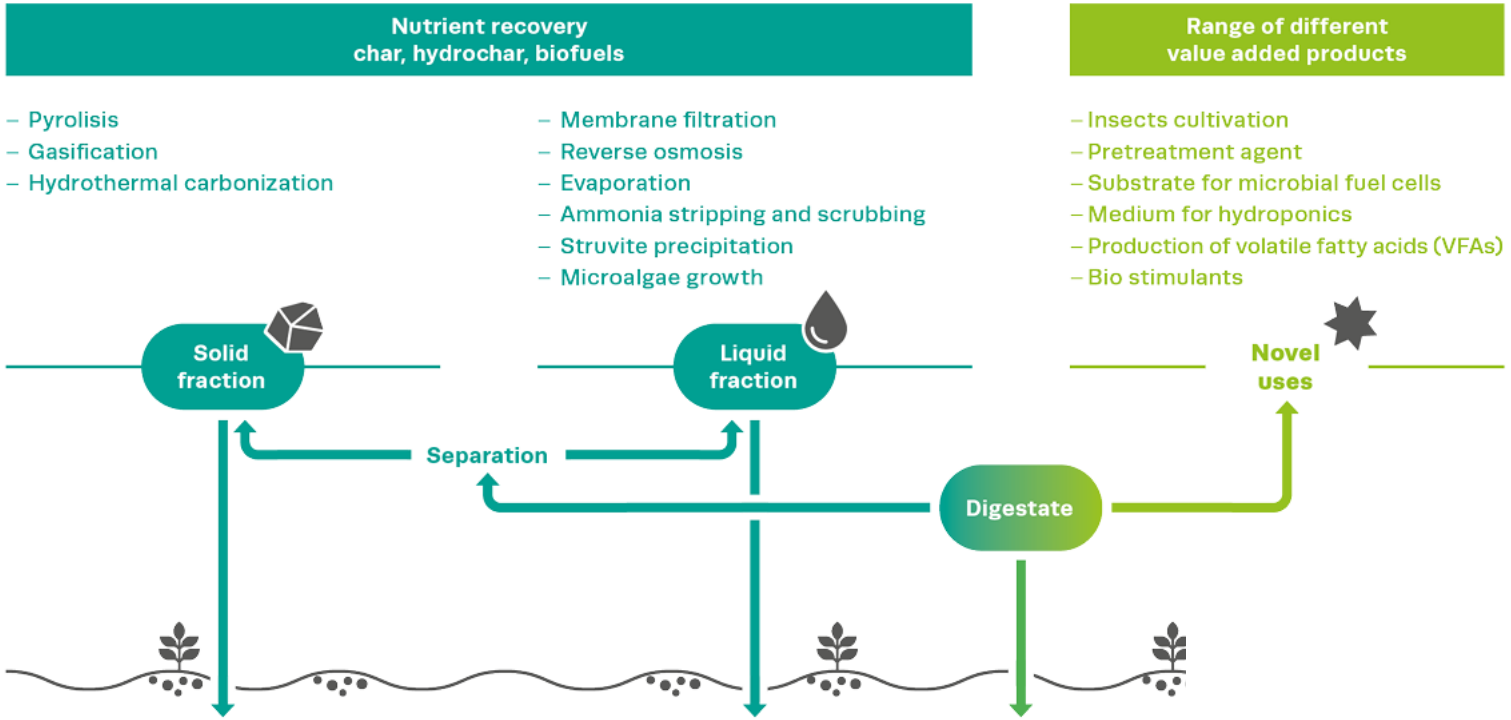
A case study of the use of digestate in Ukraine by MHP Eco Energy (2)

- Liquid digestate was applied for winter wheat in March 2020 by a surface method using a drum-hose system
- Photo – May 2020.

- Liquid digestate was applied for winter wheat in August 2019 by a surface method from a barrel
- Photo – February 2020.

Source: Olexander Dombrovsky, MHP Eco Energy, 2020

Novel digestate applications

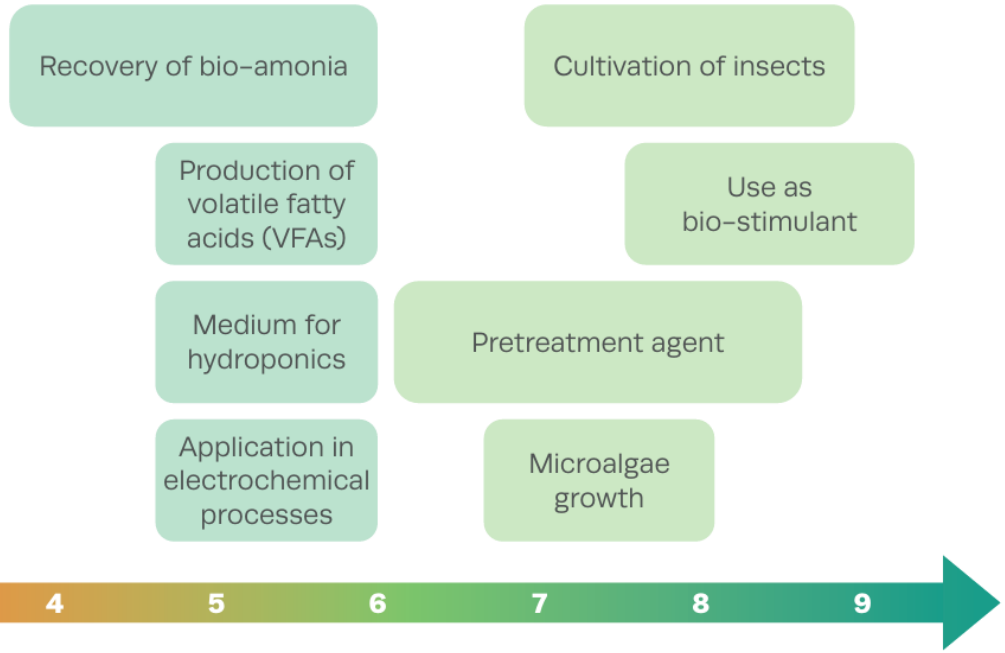


Overview of selected digestate valorisation routes

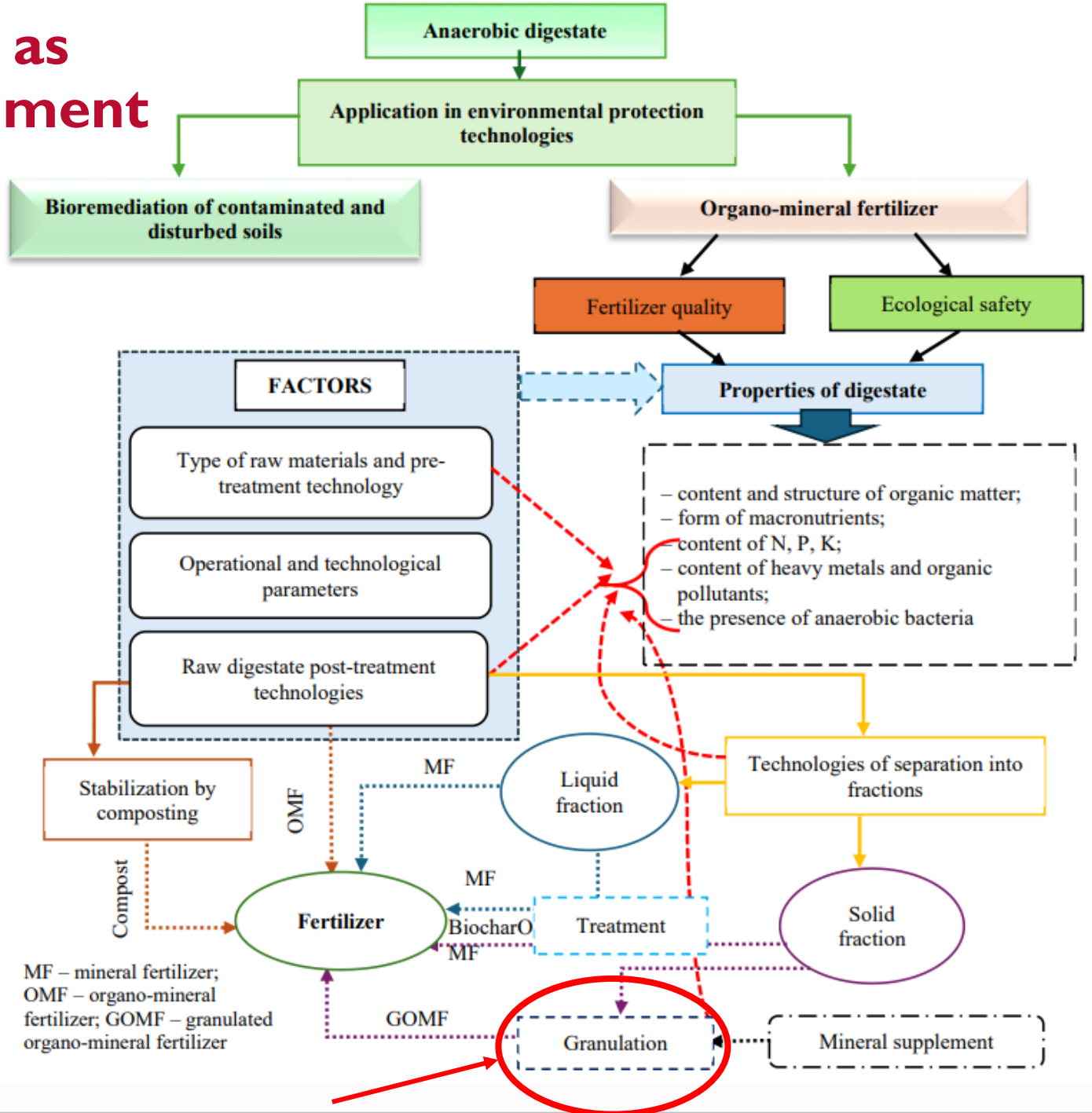
Source: *EBA. Exploring digestate's contribution to healthy soils, 2024.*

TRL of novel digestate applications

Source: *EBA. Exploring digestate's contribution to healthy soils, 2024.*



Digestate application as fertilizer and soil amendment



Source: Sipko and Ablieieva, 2024
https://doi.org/10.23939/ep2024.03.123