Horizon 2020 Programme
Research and Innovation Action

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Efficient Carbon, Nitrogen and Phosphorus cycling in the European Agri-food System and related up- and down-stream processes to mitigate emissions

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D6.9 Exploitation Brochure

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4.	IRTA
5.	ASIO TECH
6.	FCSR
7.	EMA
8.	PGP

Additional comments for the brochure:

The purpose of the exploitation brochure is to provide an overview of all five Circular Agronomics case studies and briefly introduce the technology used in each pilot installation. The pilot installations vary in capacity from less than 1 m^3/h to 3.5 m^3/h. As indicated in the brochure on page 14 in the exploitation roadmap, **the 5 technologies have reached TRL 6 to 8, which means that there are still unanswered research questions, and they are not ready for up-scaling yet**. Further research is needed to achieve market readiness.

The brochure includes technical information such as flow schemes, site descriptions, and operating conditions. The unique selling points section provides an overview of each technology's special product properties, technology-specific advantages, and legal aspects. **The main competitors and competitive advantages are not highlighted in this brochure, because they are shown in detail in deliverable 6.3**. For completeness, the most important competitors and main alternatives are listed below:

- Solar drying: N recovery in the form of Struvite, N recovery by stripping using steam or air, composting and biodrying / drying. None of these technologies is as simple and as robust as solar drying.
- Vacuum degasification: Providers of other stripping units. However, the PONDUS-N process has reduced capital and operational costs.
- Microfiltration: Digestate centrifugation or membrane filtration and the use of clarified fractions by means of irrigation systems other than drip lines (e.g. sprinklers pivot). The MDF system capital and operational (reduction in energy demand) costs.
- K-Struvite recovery: Other companies selling struvite reactor systems. However, these systems mainly operate in municipal wastewater and not in industrial/food-industry wastewater.
- Acid whey treatment: Competitors in the field of acid whey management are companies dealing with membrane separation in dairy industry. However, the application of nanofibrous membranes have lower production costs.

Circular Agronomics

CIRCULAR AGRONOMICS

Circular solutions
for **carbon** and **nutrient management**

5 INNOVATIVE TECHNOLOGIES

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Horizon 2020

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INTRODUCTION

WHY CIRCULAR AGRICULTURE?

Because a good management of carbon (C), nitrogen (N), phosphorus (P) and potassium (K) in agriculture is crucial to maintain a fertile and healthy soil and allow adequate plant growth. Therefore, high nutrient use efficiency (NUE) and sustainable soil management practices are required. The European Green Deal, in particular, the Farm to Fork strategy addresses the reduction of nutrient losses by at least 50% while ensuring soil fertility. The use of fertilisers should be reduced by at least 20% by 2030. Member States will develop integrated nutrient management plans to reduce and prevent pollution from excessive use of fertilisers, while encouraging nutrient recycling to produce bio-based fertilisers.

CIRCULAR AGRONOMICS THE PROJECT

Circular Agronomics has developed solutions for a more sustainable circular management of nutrients by analysing flows, stocks, and emissions from different European agricultural, livestock and food processing practices. The outcomes are promising: Improved NUE in agro-ecosystems, reduced greenhouse gas (GHG) emissions, less mineral fertiliser use and decreased eutrophication potential. At the same time, Circular Agronomics included the social, economic and political dimensions. To integrate Circular Economy and Resource Efficiency into a more sustainable agriculture, the entire EU agri-food system from farmers to consumers was involved.

THE 5 INNOVATIVE TECHNOLOGIES

IN FIVE CASE STUDIES NUTRIENT RECOVERY TECHNOLOGIES HAVE BEEN FURTHER DEVELOPED:

1. SOLAR DRYING
2. VACUUM DEGASIFICATION
3. MICROFILTRATION
4. STRUVITE RECOVERY
5. ACID WHEY TREATMENT

The brochure gives a comprehensive and short overview on each technology.

- To date the technologies reached TRL 6 to 8.
- They are applied to solid or liquid fraction of agricultural digestate or wastewater and waste streams from food industry.
- The scale of installations varies from a capacity less than 1 m^3/h towards 3.5 m^3/h.

Manure or digestate generated in a biogas plant is usually applied directly to agricultural land to use the nutrients. Due to intensive agriculture practices, this leads to an excessive fertilisation, especially with nitrogen, eutrophication of soil and water bodies and climate-relevant N_2O emissions.

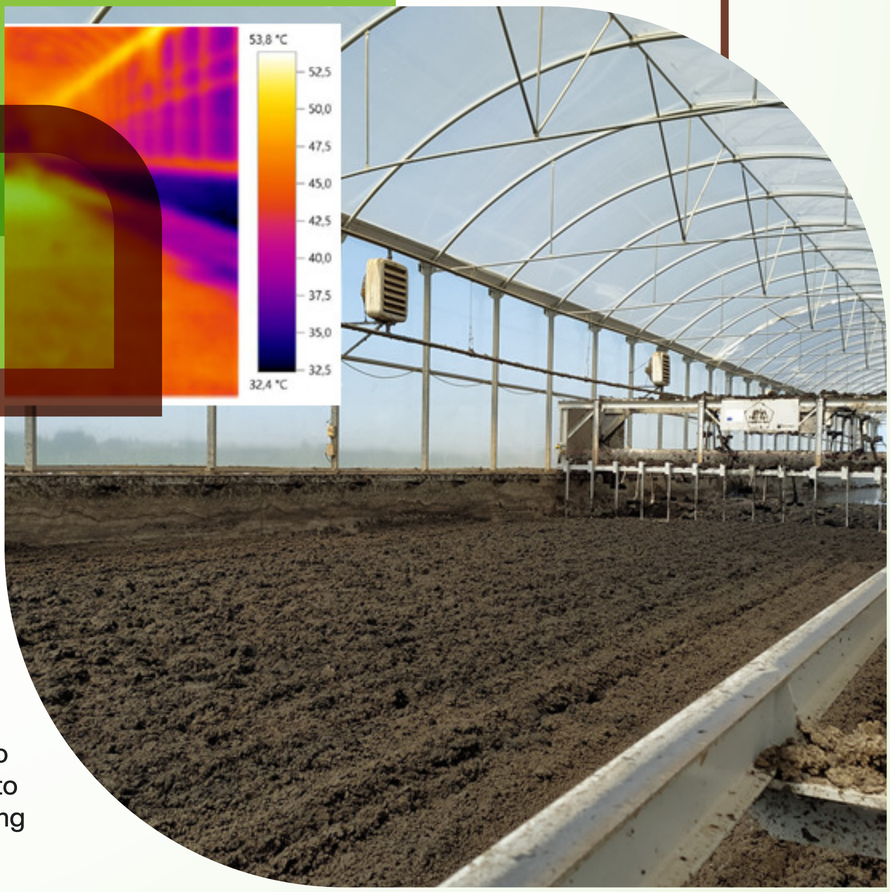
The handling of the semi-liquid digestate (3-8% of dry matter content) is challenging. Three innovative technologies in **(1) Spain, (2) Germany** and **(3) Italy** have been tested to treat the massive volume of manure with different approaches.

Food industries produce often nutrient-rich wastewater. At the same time, European agriculture is dependent on nutrient imports and suffers from water shortage. Nutrients and water are becoming increasingly scarce. In order to both recover the nutrients and reuse the water, the efficient treatment of industrial wastewater is necessary. Two promising technologies in **(4) Belgium** and **(5) the Czech Republic** were applied to potato and milk processing wastewater.

01

SOLAR DRYING OF MANURE AND DIGESTATES

SEMI-INDUSTRIAL PILOT PLANT IN CATALONIA (SPAIN)



Description:

The Institute of Agrifood Research and Technology IRTA and the company EMA Depuració have developed a process line, which includes an efficient solid-liquid separation (centrifuge) in combination with a solar/thermal drying process for the digestate and its solid fraction to obtain high-quality fertiliser. Ammonium salts are fixed by acidification to obtain a dried and stable product, allowing to apply it according to crop needs and avoiding emissions to the air and to water bodies.

The semi-industrial pilot plant in Catalonia operated by Porgaporcs treated 2.5 m³/h digested pig manure. The solar drying process obtained a stabilised product with a dry matter content of 85% after 10-30 days of the tested solar drying. The product is rich in nitrogen, phosphorus and potassium (TN: 3.8%, P_2O_5: 7% and P_2O_5: 0.5% of dry matter). In a further step, the treatment of the liquid fraction with a stripping process to recover ammonium sulphate is tested. Off-gas from the dryer is treated in a biofilter to eliminate odors. Active N-species (NH_3, N_2O) have already been retained in the solid dry fraction.

Operating Conditions

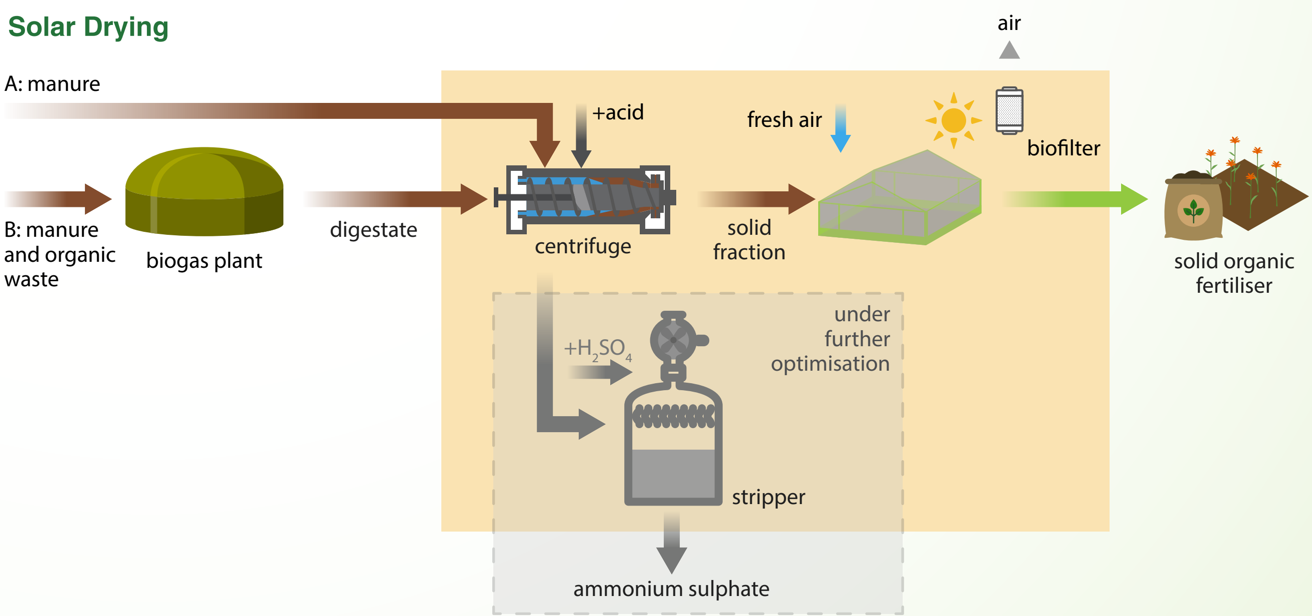
Temperature (naturally achieved)	30-60 °C
pH (after acidification)	5.5
Time	10-30 days

Economics:

- **Capacity of up-scaling:** 15 m³/h raw digestate
- **Estimated costs:** 3-4 €/m³ raw digestate for acidification and solar drying, revenues for product not known and not included
- **Biggest share of costs:** Chemical cost for acidification and investment costs
- **Recommendation:** Regions with warm summers and many sun hours along the year or site with excess thermal heat

Unique Selling Points

- Combined calorific and solar power
- Simple handling and storage of digestate because of 85% dry matter content
- Recovery rate of about 60% TN, 77% P_2O_5 and 32% K_2O of the input nutrient
- Holistic technology without waste streams
- Production of organic bio-fertilisers according to European legislation



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02 VACUUM DEGASIFICATION OF AGRICULTURAL DIGESTATE

PILOT PLANT IN BRANDENBURG (GERMANY)

Description:

The PONDUS-N process patented by Pondus® Verfahrenstechnik GmbH and further developed by KWB aims at recovering ammonia and carbon dioxide from agricultural digestate as base materials for industrial fertiliser production. The decoupling of N depleted digestate and inorganic nitrogen allows for flexible fertilisation and minimizes undesirable losses to the environment while still providing all necessary nutrients to the soil. A thermo-alkaline pre-treatment is used to increase the content of free ammonia, which is then driven out in the degasification column by a recirculated gas stream or external air input while negative pressure is applied. In the absorber, it is brought into contact with a calcium sulphate solution. The resulting di-ammonium sulphate and calcium carbonate can be used as a source material for fertiliser production.

In the project, a pilot plant with a capacity of 1 m^3 storage volume and a maximum continuous flowrate of 0.15 m^3/h has been installed in Brandenburg operated by KWB. In batch trials an inorganic N removal rate of 95% was proven. For a continuous operation mode, removal rate of 80-85% is assumed.

Operating Conditions

Temperature	55—70 °C
Absolute pressure	800—900 mbar
pH	8.5—9.5
Gas flow to liquid	200-500 L/L

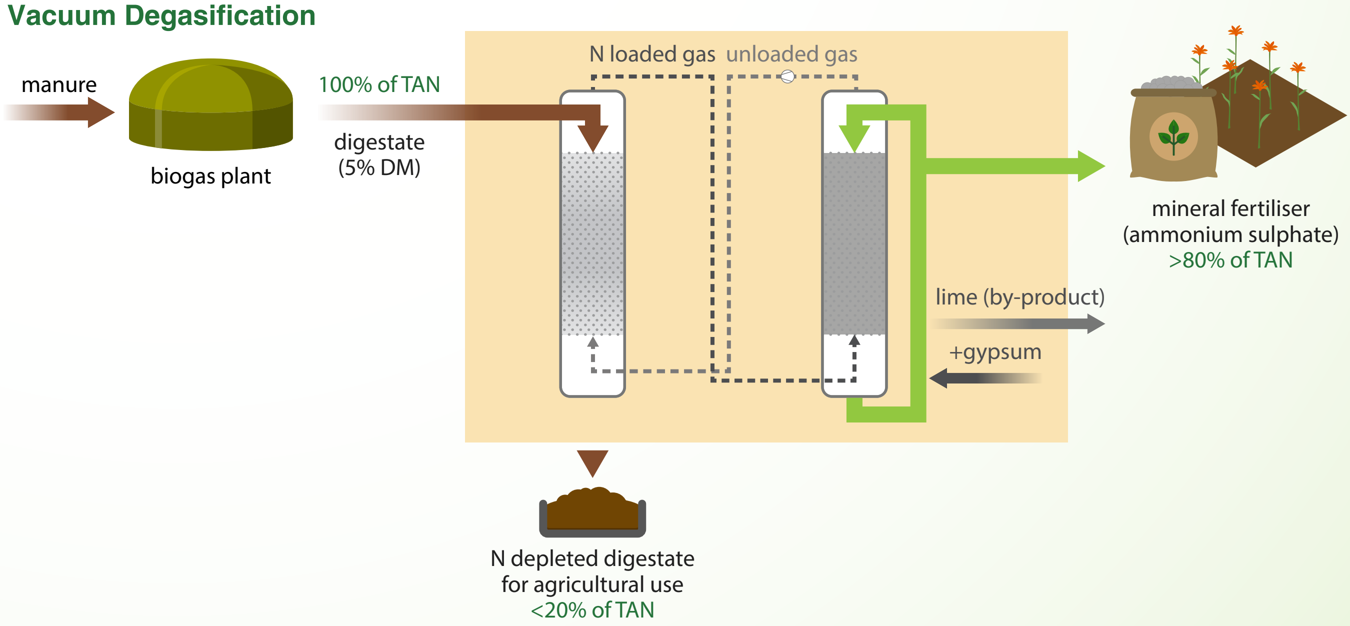
Economics:

- **Capacity of up-scaling:** 15 m³/h raw digestate
- **Estimated costs:** 1.5-2.0 €/m³ raw digestate
- **Biggest share of costs:** Investment costs and electricity
- **Recommendation:** Investment costs have major share. Therefore, this technology is economically for plants with a high capacity (>15 m³/h).

Unique Selling Points

- >80% removal of total ammonia nitrogen (TAN) achievable + carbon capture storage
- Heat can be recovered and reused, pH-adaption can be realised by CO_2-stripping (minimalization of external heat and aggressive chemicals)
- N depleted digestate can be used as soil conditioner
- Decoupling N from digestate helps comply the EU Nitrates Directive
- Production of mineral fertiliser or its base material according to the EU Fertiliser Product Regulation

Vacuum Degasification



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03

MICROFILTRATION OF DIGESTATE FOR FERTIGATION

PILOT PLANT IN EMILIA-ROMAGNA (ITALY)

Description:

The integrated Microfiltered Digestate to Fertigation (MDF) system, developed by CRPA Foundation in collaboration with Saveco Wamgroup (microfiltration) and Netafim Italia (fertigation) aims at distributing the digestate/slurry, mixed with water, through a drip irrigation system. The raw digestate is first separated into a palatable solid fraction and a liquid fraction. The latter is subjected to microfiltration to obtain the microfiltered digestate to be used on growing crops through drip lines. The microfiltered represents the largest portion of the incoming raw digestate, and the others are the solid fraction deriving from horizontal screw press and the dense fraction from the microfilter. The solid and dense fraction can be used for soil tillage.

In the scope of Circular Agronomics, a pilot plant was installed at CAT Correggio cooperative, Emilia-Romagna with a flow rate of 5 m^3/h. The microfiltrate accounts for 85% of the input volume and can directly be used in surface drip lines at 1 bar pressure.

Flow Rates

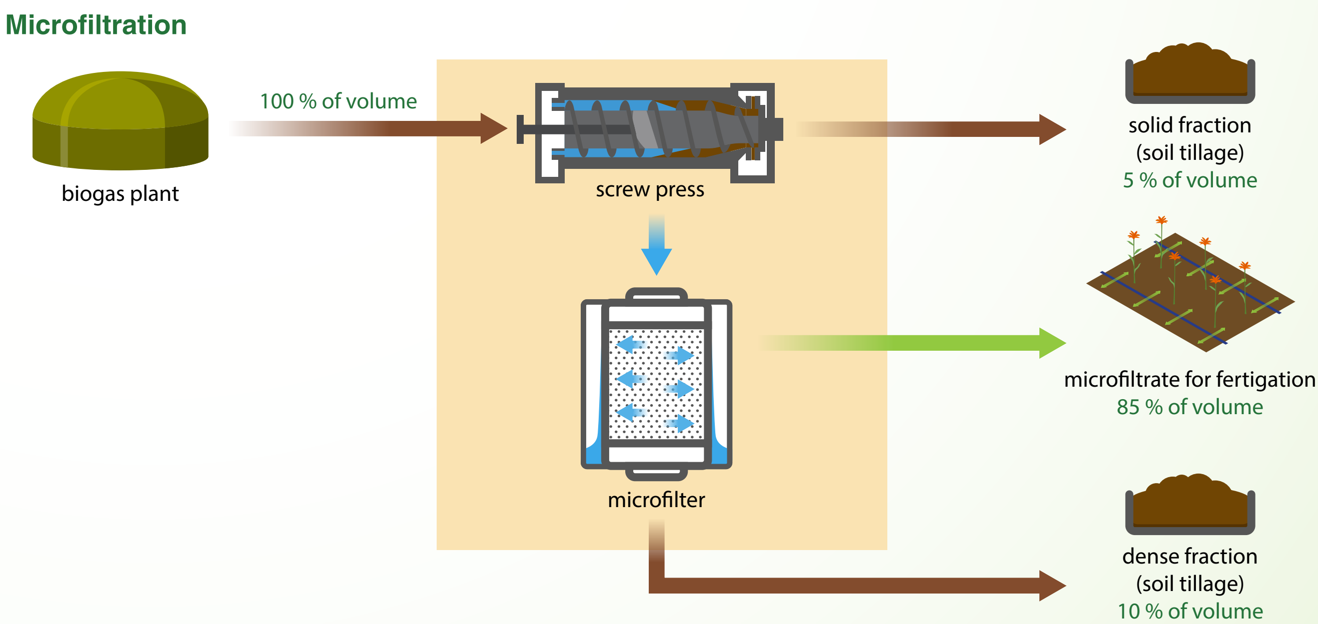
Microfilter	~4-6 m^3/h
Drip irrigation	~20 m^3/ha/h

Economics:

- **Capacity of up-scaling:** 15 m^3/h raw digestate
- **Estimated costs:** Microfilter: around 0.5 €/m^3 raw digestate, Drip line irrigation + microfilter: 2,100 €/ha (business-as-usual about 1,800 €/ha)
- **Composition of costs:** Investment costs and electricity
- **Note:** Due to low overall costs, MF reaches cost sufficiency also at lower capacities (<3 m^3/h)

Unique Selling Points

- Moderate cost and low maintenance equipment
- Reduction of greenhouse gases (up to 46% N_2O), ammonia emissions (up to 89%) and nitrate leaching/run-off on the field
- Minimize water and energy consumption
- A complete pilot plant at farm scale developed and validated (TRL 7-8)
- Replacing mineral fertiliser according to the EU Green Deal



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04

K-STRUVITE RECOVERY

PILOT PLANT IN IEPER (BELGIUM)

Description:

In Ieper (Belgium) a combined phytase treatment of soybean wastewater with integrated N-struvite (NH_4MgPO_4) or K-struvite ($KMgPO_4$) recovery was developed by NuReSys and tested on laboratory and pilot scale (0.5 m^3/h). In the first step phosphorus as phytic acid is hydrolyzed to release ortho-phosphate by adding phytase enzymes. After anaerobic processing N-struvite can be produced by pH adjustment (no $MgCl_2$ needed). An alternative is producing K-struvite at pH 8.8-9.5 with a limited amount of $MgCl_2$ added.

K-struvite formation is only possible if NH_4 is absent. Therefore, K-struvite precipitation is only feasible after an additional aerobic treatment step.

Operating Conditions

Temperature	25 – 40 °C
pH	8.8-9.5
Hydraulic retention time	60 min

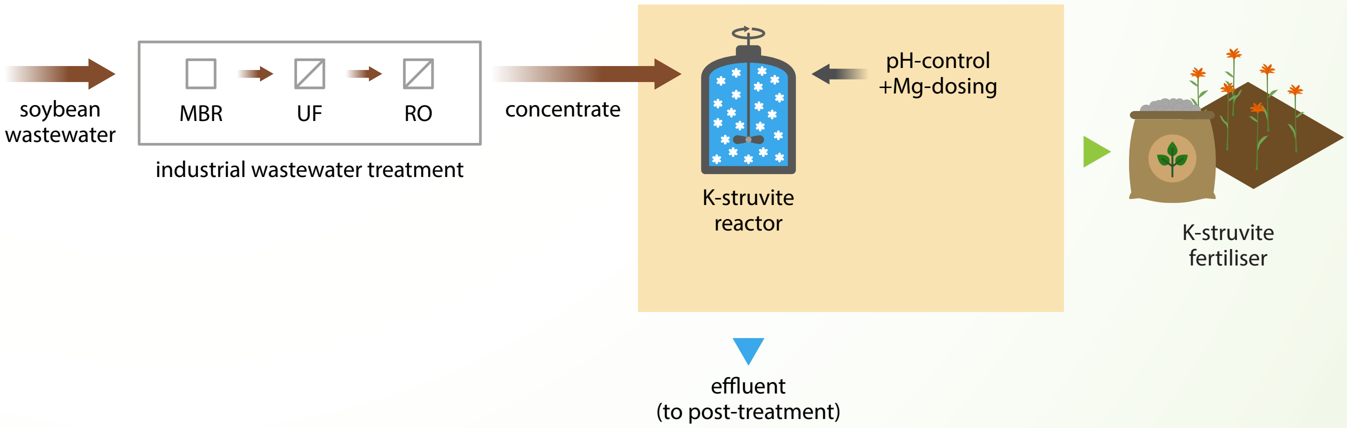
Economics:

- **Capacity of up-scaling:** 15 m³/h RO brine resulting from effluent recovery
- **Net costs:** 0.2 €/m³ RO brine (1 €/m³ RO brine for treatment and 0.8 €/m³ RO brine revenue for K-struvite)
- **Biggest share of costs:** Investment costs and costs for NaOH and $MgCl_2$
- **Optimizing potential:** Higher capacity reduces specific capital costs

Unique Selling Points

- 80-90% P recovery possible
- 60-65% conversion of phytic acid to soluble PO_4-P with phytase enzymes possible
- K-struvite formation can be added within an existing treatment process as an add-on
- Production of economically valuable non-soluble K-/N-salts (slow release fertiliser)
- Production of bio-based fertiliser according to the EU Fertiliser Product Regulation

K-Struvite Recovery



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05

NOVEL MEMBRANES FOR ACID WHEY TREATMENT

PILOT PLANT IN MADETA (CZECH REPUBLIC)

Description:

In dairies and milk processing industries, acid whey is considered as waste and often discharged into a wastewater treatment plant. However, acid whey can be reused as soil conditioner, which was investigated in this case study in Madeta (Czech Republic). As a treatment process new electrospun nanofibrous membranes (ENM) with pores up to 200-400 nm to ensure efficient separation where tested. ENM can be used (as an alternative to centrifuges) in the acid whey management to remove fats from acid whey before the thickening process via nanofiltration. In the scope of Circular Agronomics, a pilot plant with a capacity of 2.5 m^3/h has been operated by ASIO TECH to evaluate its performance.

After treatment, the product has the following composition: TSS = 18%, TC = 7.4%, TN = 0.2%, TP = 1.9 g/kg, TK = 1.7 g/kg and $N\text{-}NH_4$ = 200 mg/L. These substrates can be used for anaerobic digestion or directly as a soil conditioner.

Technological data ENM module

Nominal flux	15 - 40 lmh
Pore size	200 – 400 nm
Filtration pressure	0.05 – 0.4 bar

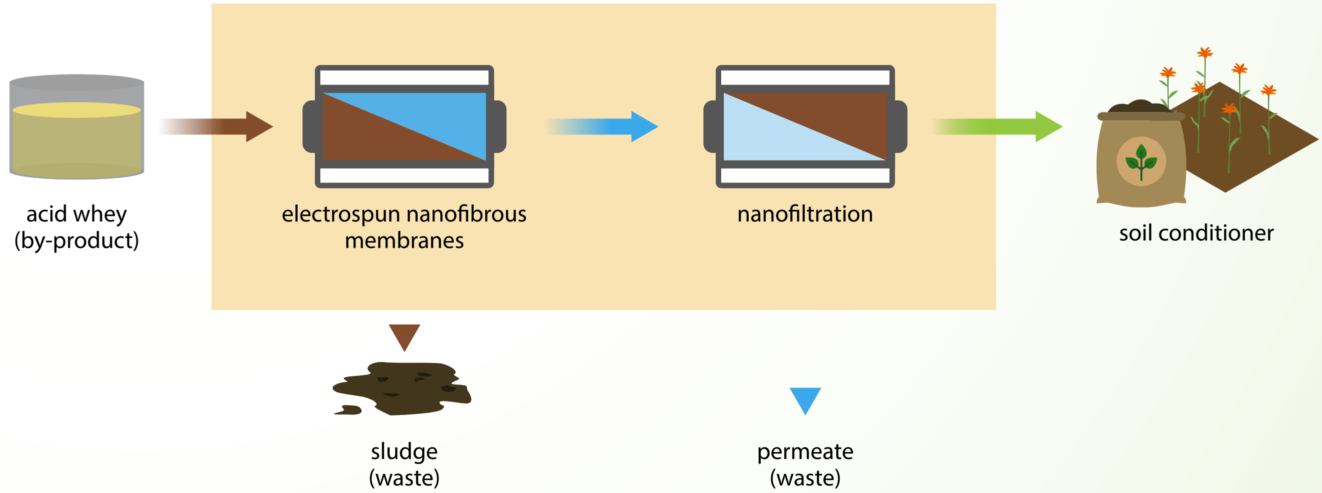
Economics:

- **Comparison of ENM (up-scaling) with a conventional centrifuge:** Treatment of 15 m³/h raw acid whey
- **Costs:** 0.4-0.5 €/m³ acid whey with the ENM (0.6-0.7 €/m³ acid whey with the centrifuge)
- **Biggest share of costs:** Investment costs for the ENM
- **Optimizing potential:** Higher capacity reduces specific capital costs

Unique Selling Points

- Valorisation of acid whey (waste product) as soil conditioner
- Low energy consumption of ENM of 0.6 kWh/m³
- ENM also applicable for a more energy efficient digestate thickening compared to a centrifuge (up-scaling under research)
- High amounts of acid whey in the EU milk industry presents a big market

Acid Whey Treatment



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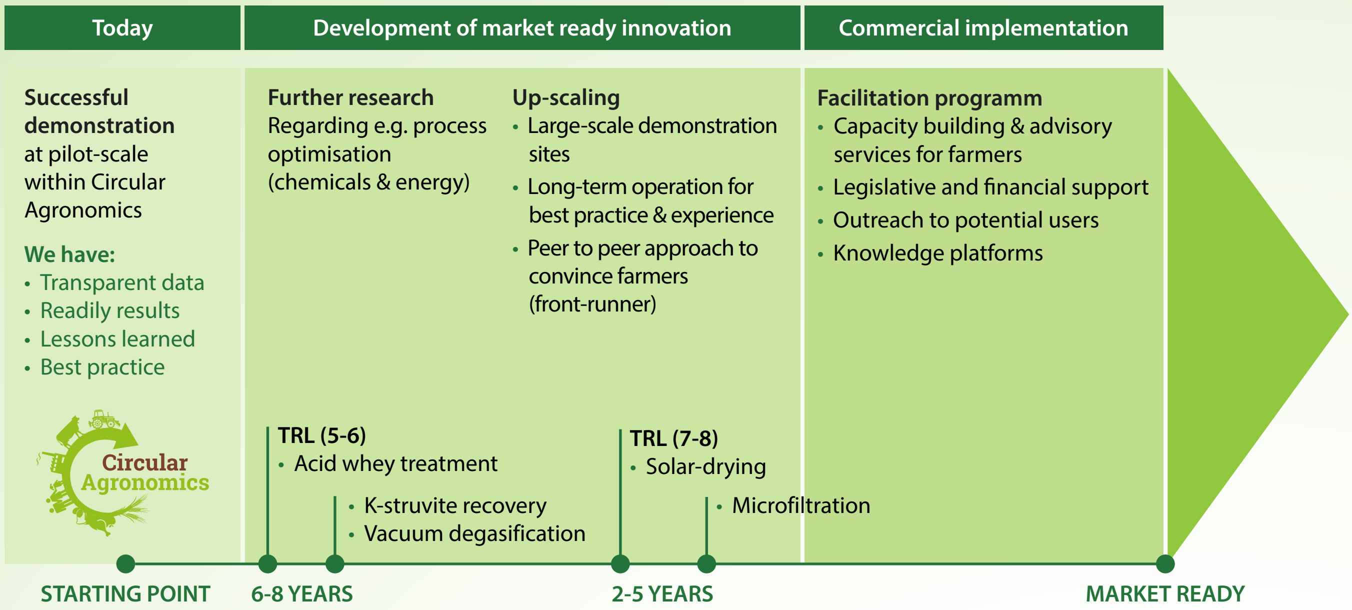
Exploitation roadmap



The five technologies delivered promising result at pilot-scale. The biggest challenges are long-term operation (solar-drying) and up-scaling of the dimensions (microfiltration). In some cases, there are still open research questions and data gaps, especially for vacuum degasification, K-struvite recovery and acid whey treatment. Potentials for optimisation and improvement for a final market ready technology have to be exploited for all technologies. Besides, the market conditions including the legal framework should be updated to facilitate the actual uptake of new innovative and circular technologies.

- The consumption of chemicals, especially in buffer systems, and the use of energy (thermal energy) is crucial for the sustainability of the technology, particularly for vacuum degasification and K-struvite recovery, but also for solar-drying system.
- Regional conditions are decisive for the cost effectiveness. Transporting distances for digestate or manure over 100 km (and related greenhouse gas emissions) can be avoided with the technologies by having similar costs and enable regional nutrient recycling.
- The capital costs are crucial (up to 70% for a capacity of 15 m^3/h of total costs). Hence, financial support is required like one-off investment subsidy for environmental-friendly technologies, nutrient recovery/recycling quota or "green" taxation of recovered nutrients and circular products.
- The products will enter the market either as fertilisers, as manure or as waste streams with significant differences in marketing values. Hence, the legal framework and the relevant product definitions are very important and should focus on product quality instead of origin.

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