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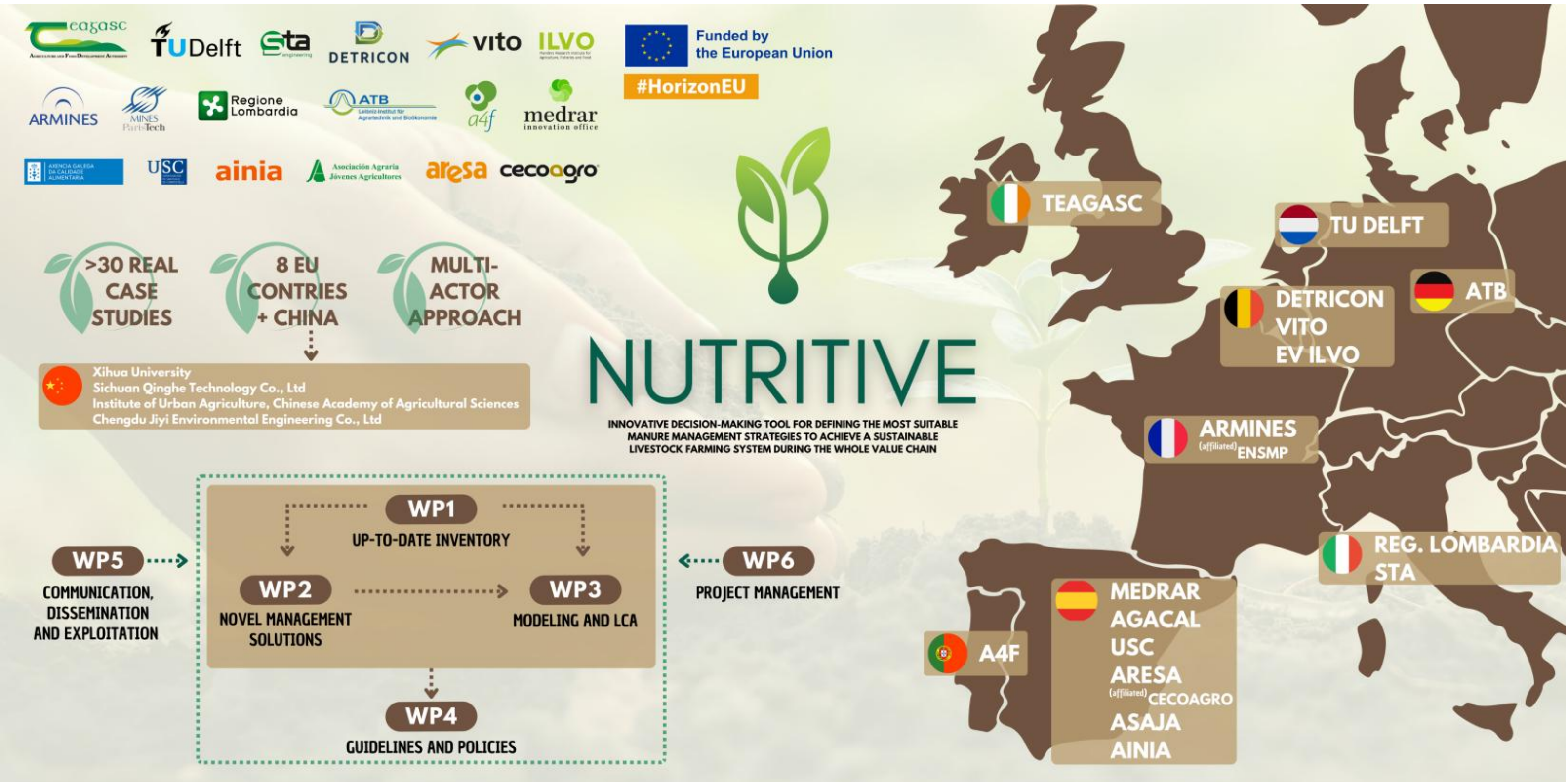
Novel manure management strategies and technologies info-pack



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First Point Control. An early-intervention strategy to reduce ammonia emissions and improve animal health

State of the Art

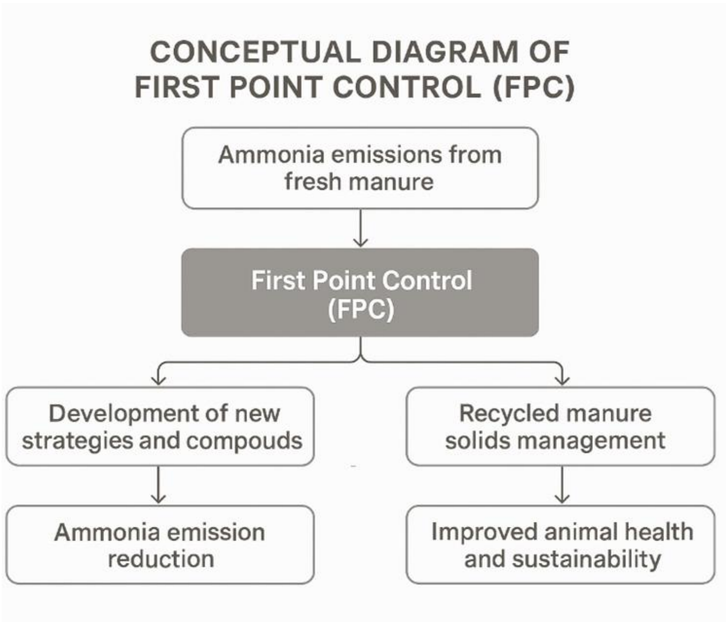
The First Point Control (FPC) initiative introduces an early-intervention strategy to reduce ammonia emissions by targeting the biochemical and microbial processes that occur immediately after manure excretion, across ruminants and swine systems. Its dual-phase framework combines in vitro screening of chemical additives, enzymatic inhibitors, and novel compounds with subsequent validation under commercial farm conditions to ensure both effectiveness and practical scalability. Beyond fresh manure mitigation, FPC also addresses challenges associated with recycled manure solids (RMS) used as bedding in ruminant operationsby developing treatments that improve environmental performance and animal health while preserving the advantages of RMS

First Point Control Description

The study employs a controlled in vitro experimental platform to evaluate strategies for reducing ammonia emissions from fresh manure (Objective A) and microbial loads in recycled manure solids (RMS) (Objective B).

Objective A, the methodology follows three phases—model characterization, compound screening, and on-farm validation—using 5-L PVC containers filled with 2 L of fresh manure, equipped with slatted lids to simulate airflow and continuously monitored for ammonia using a DOL 53 electrochemical sensor over 1–5 days.

Objective B follows an analogous three-phase structure—RMS characterization, antimicrobial testing via MIC and MBC assays, and evaluation of microbial load reduction of the selected compound candidates—using similar PVC units housed in thermostatic baths (21–24 °C) for 1–10 days to assess effects on key bacterial groups (E. coli, Klebsiella spp., Staph. aureus, Strep. uberis). Across both objectives, serial or multi-unit designs allow comparison of multiple treatments and controls, and microbial assays include procedures for isolation of non-pathogenic bacterial families to understand broader shifts in microbial community dynamics.



Main benefits expected

- ❖ Assess ammonia exposure in dairy and swine from manure contact.
- ❖ Identify compounds that reduce ammonia emissions in fresh manure by >70%.
- ❖ Characterize RMS and study microbial dynamics under farm conditions.
- ❖ Emission reduction strategies and RMS management guidelines to improve animal welfare.

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Dietary interventions. Nitrogen-use efficiency in livestock by enhancing the conversion of ditary nitrogen into productiv outputs

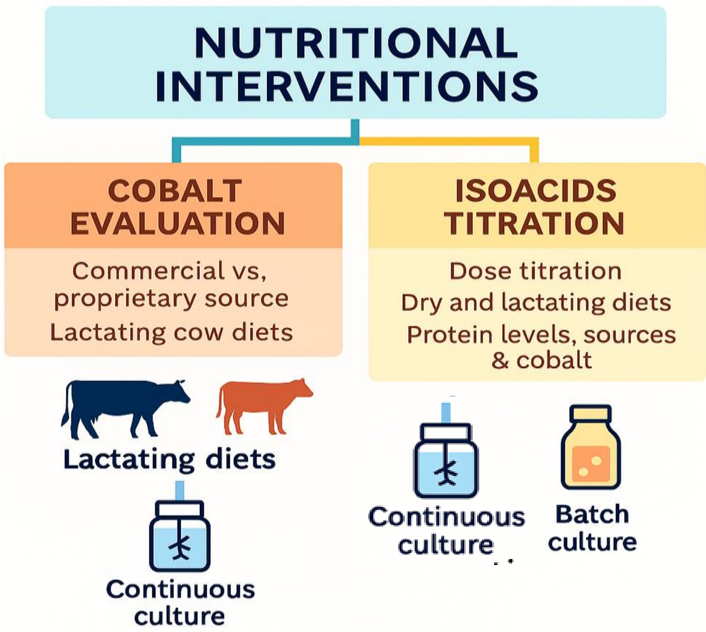
State of the Art

The Dietary Interventions initiative focuses on improving nitrogen-use efficiency in livestock by enhancing the conversion of dietary nitrogen into productive outputs, thereby reducing nitrogen excretion and ammonia emissions at the source. This proactive nutritional approach complements manure-management strategies while delivering environmental benefits through lower nitrogen losses, economic gains via improved feed efficiency, and better animal welfare through optimized diets. Central to this strategy is increasing microbial synthesis and fiber digestibility in the rumen through targeted supplementation—such as cobalt, which supports vitamin B12 production and fibrolytic bacterial growth, and branched-chain fatty acids (isoacids), which fibrolytic microbes cannot synthesize without external supply.

Nutritional Interventions Desscription

Materials: The study uses four 2-L continuous stirred-tank reactors (CSTRs) designed to mimic the rumen environment, with controlled temperature, agitation, synthetic bovine saliva infusion, and automatic pH regulation to maintain anaerobic fermentation conditions while preserving a stable microbial community. Liquid and gas samples are collected from the reactors for analysis, and the system allows precise control of hydraulic and solid retention times to replicate ruminal bioprocesses. To evaluate treatment effects on methane production, an additional batch culture system with 18 stirred, sealed vessels measures gas output in real time using CO_2 traps and micro-flowmeters, with all data recorded through dedicated software.

Operational conditions: The CSTR system operates under controlled rumen-like conditions, including liquid and solids dilution rates of 10% and 5% per hour, retention times of 10 hours (HRT) and 20 hours (SRT), a daily feed input of 50 g DM, and tightly regulated fermentation at 39 ± 1°C with an automatically maintained pH of 6.1–6.9. In contrast, the batch culture system uses a 50/50 inoculum-to-buffer ratio, receives an initial 25 g DM feeding, and runs for 24–72 hours at the same temperature but without active pH control. Instead, pH in the batch system is passively buffered using the same synthetic saliva employed in the CSTRs.



Main benefits expected

- Evaluate the effect of nutrients from Cobalt and Isoacids on N utilization efficiency in dairy cattle diets
- Identify new nutritional approaches that enhance sustainability by reducing greenhouse gas emissions
- Examine the feasibility of using more sustainable forages with a lower greenhouse gas footprint
- Provide farmers with an innovative solution that benefits both the farm's economy and the environment

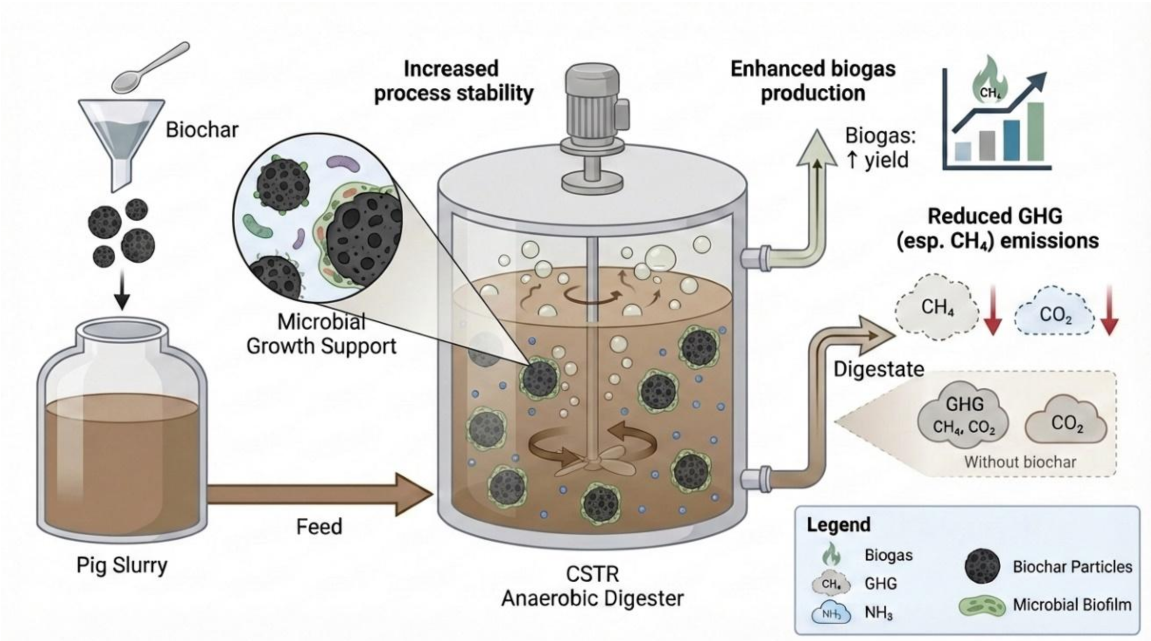
Anaerobic digestion (AD) enhanced with the addition of biochar

State of the Art

Methane emissions significantly contribute to climate change, but anaerobic digestion (AD) enables their capture and valorization as biomethane. Although AD is a key renewable energy technology, its moderate efficiency limits wider deployment. Recent studies show that carbon-based materials (CBMs) enhance AD performance by improving microbial activity, promoting direct interspecies electron transfer, and mitigating ammonia and volatile fatty acid inhibition. CBM properties, determined by feedstock and production conditions, are therefore critical for increasing methane yield and process stability.

Description of the manure management strategy/technology

Pig manure will be treated using an anaerobic digestion reactor, modifying parameters such as Hydraulic retention time (HRT), organic rate loading (OLR) and biochar dosage supply. At the same time, the quality of the effluent obtained and emissions of CH4 and other GHGs will be evaluated. Previously, the adequate Biochar dosage will be evaluated by biochemical methane potential test (BMP) following the VDI-4630 standard.



Main benefits expected

- **Enhanced methane yield and process efficiency** through improved microbial activity and accelerated electron transfer mechanisms (e.g., DIET), overcoming the moderate efficiency of conventional anaerobic digestion.
- **Improved process stability** by mitigating common inhibitors such as ammonia and volatile fatty acids, reducing the risk of process failure under high loading or suboptimal conditions.
- **Greater robustness and resilience of microbial consortia**, supported by increased microbial diversity, biofilm formation, and selective enrichment of key methanogenic populations.
- **Valorization of waste-derived carbon-based materials**, providing an added-value application for biochar/hydrochar while supporting circular economy and decarbonization strategies.

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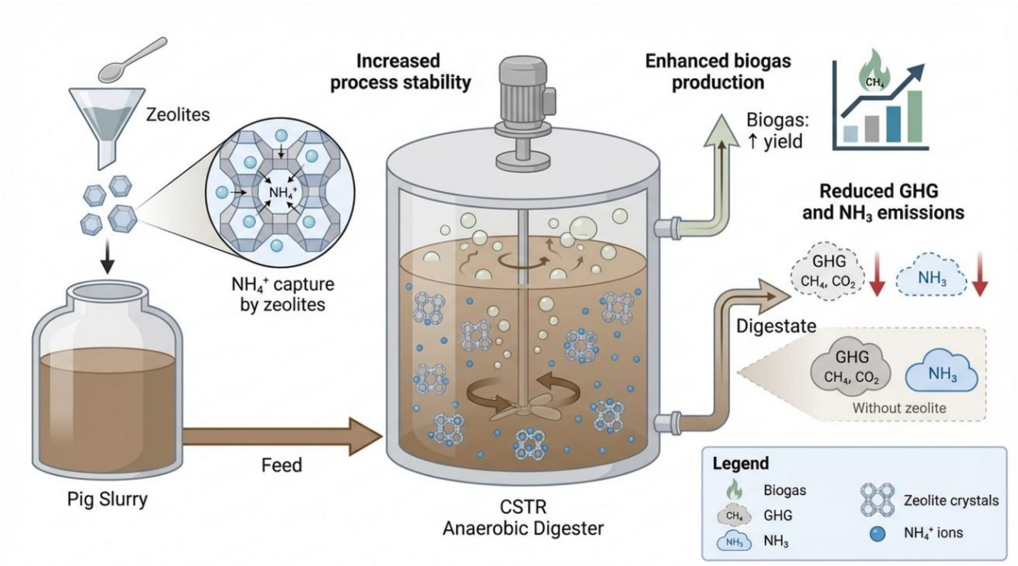
S/T 4. Anaerobic digestion (AD) enhanced with the addition of zeolites

State of the Art

Ammonia emissions represent a significant environmental and health concern due to their role in particulate matter formation and ecosystem alteration. In anaerobic digestion (AD), ammonia is generated during protein degradation and can severely inhibit microbial activity, particularly methanogenesis, under high concentrations. Zeolites have emerged as a promising additive for AD systems due to their ability to selectively adsorb ammonium through cation exchange mechanisms. Natural zeolites, such as clinoptilolite, offer a cost-effective solution with proven adsorption capacity and affinity for ammonium ions. When integrated into AD processes, zeolites not only mitigate ammonia inhibition but also enhance biogas production and process stability, supporting their potential role in reducing both methane and ammonia emissions along the manure management chain.

Description of the manure management strategy/technology

Pig manure will be treated using an anaerobic digestion reactor, modifying parameters such as Hydraulic retention time (HRT), organic rate loading (OLR) and zeolite dosage supply. At the same time, the quality of the effluent obtained and emissions of NH3 and other GHGs will be evaluated. Previously, the adequate zeolite dosage will be evaluated by biochemical methane potential test (BMP) following the VDI-4630 standard.



Main benefits expected

- **Reduction of ammonia inhibition in anaerobic digestion**, lowering the risk of process failure and methane yield losses under high-nitrogen feedstocks.
- **Improved biogas and methane production**, driven by enhanced microbial performance under reduced ammonia stress.
- **Simultaneous mitigation of gaseous emissions**, enabling the control of both methane and ammonia within integrated AD–zeolite systems.
- **Cost-effective and scalable solution**, based on the use of abundant natural zeolites with proven adsorption kinetics and selectivity.
- **Enhanced process robustness**, increasing tolerance to feedstock variability typical of manure-rich and organic waste mixtures.

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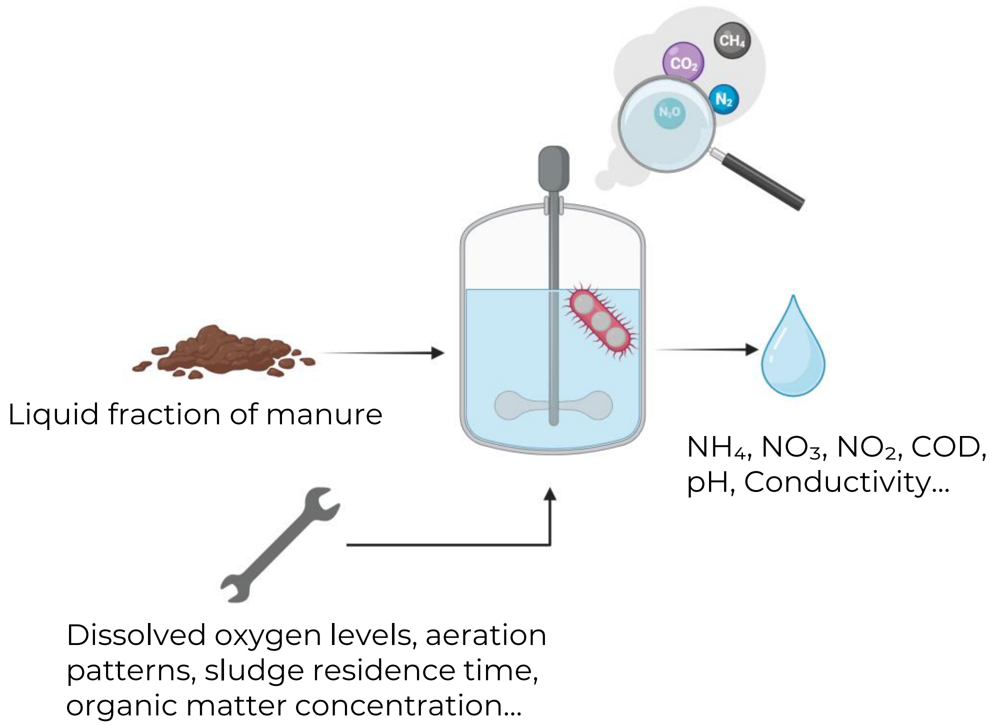
Nitrification – denitrification (NDN)

State of the Art

The NDN process is the most widely used biological process for reducing the presence of organic matter and nutrients in waste streams such as manure. In this process, bacteria transform ammonium into nitrogen gas and organic matter into CO_2. However, these metabolic pathways produce other secondary compounds such as N_2O and CH_4.The capacity of this process is well known, but more knowledge is necessary about how operating parameters influence levels of greenhouse gas emissions (mainly CH_4 and N_2O) during biological treatment.

Description of the manure management strategy/technology

Manure will be treated using a biological NDN process, modifying parameters such as oxygen supply, aeration patterns, sludge residence time, etc. At the same time, the quality of the effluent obtained and emissions of N2O and other GHGs will be evaluated.



Main benefits expected

- Obtain experimental N_2O and other GHG emission rates for different operating parameters rates that can be applied to subsequent studies to complement the life cycle analyses of other treatments
- Identify operating parameters that allow an adequate wastewater treatment with lower GHG emissions
- Reduction of the overall environmental footprint of the NDN process

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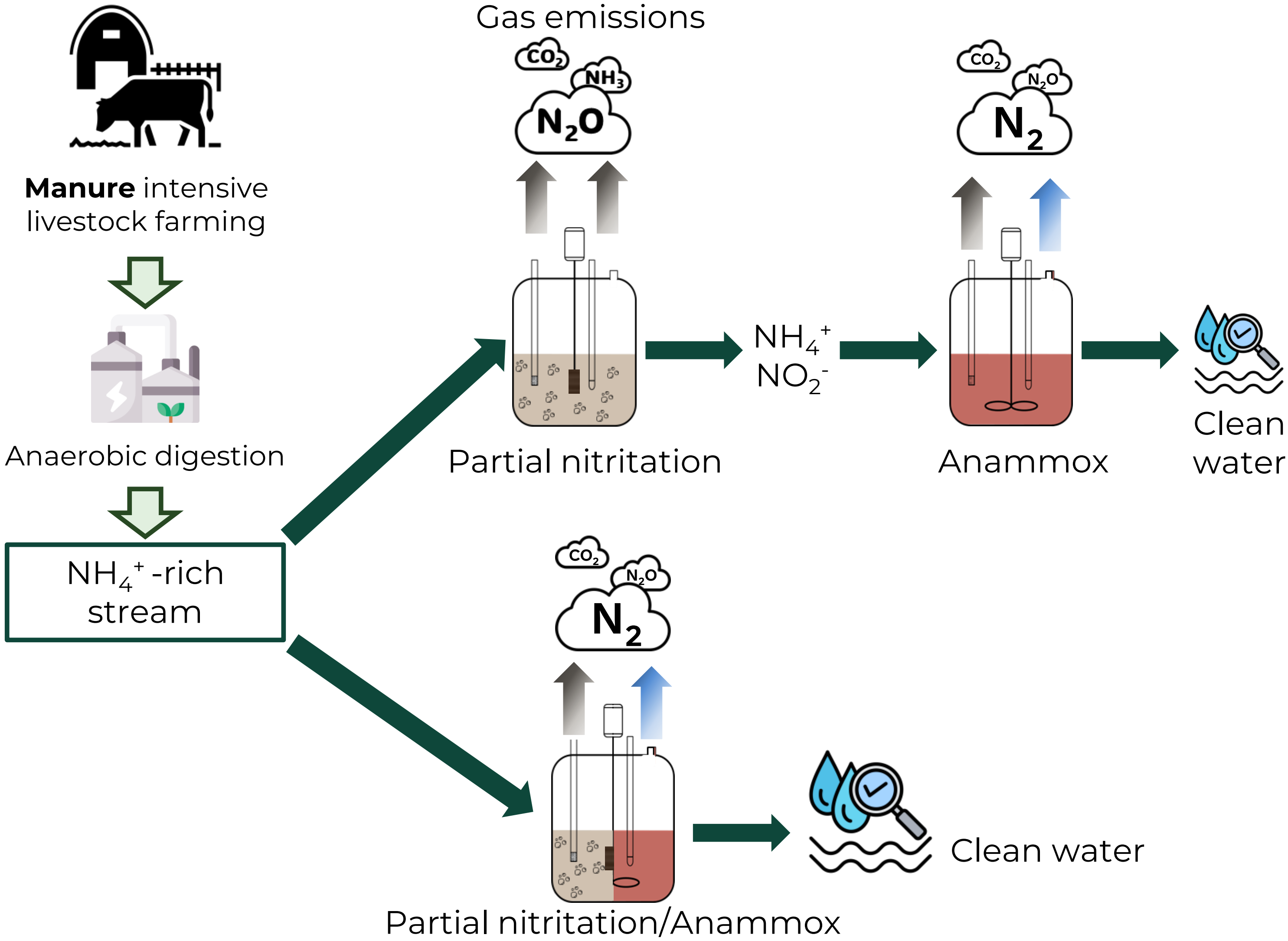
Partial nitritation/anammox (PN/AMX)

State of the Art

Partial nitritation/anammox (PN/AMX) processes constitute a resource-efficient alternative to conventional nitrification-denitrification processes for biological nitrogen removal from liquid waste. These processes couple aerobic partial nitritation, in which approximately 50 % of ammonium is oxidized to nitrite by ammonia-oxidizing bacteria, with anaerobic ammonium oxidation (anammox), in which the remaining ammonium is transformed, together with nitrite produced by the bacteria, into nitrogen gas. As a result, PN/AMX processes significantly reduce aeration requirements and eliminate the need for external organic carbon, enabling lower energy consumption and enhanced anaerobic digestion of organic matter. PN/AMX can be implemented in either a one- or a two-stage configuration. Although one-stage systems are often regarded as more economically attractive, their environmental performance, particularly regarding gaseous emissions such as nitrous oxide (N_2O) and ammonia (NH_3), as well as effluent quality stability under variable conditions, remains insufficiently characterized and, in some cases, contradictory.

Description of the manure management strategy/technology



Main benefits expected

- Reduced operational costs due to lower aeration requirements compared to conventional nitrification-denitrification processes
- Minimal excess sludge production
- Potential reduction of gas emissions compared to conventional nitrogen removal processes

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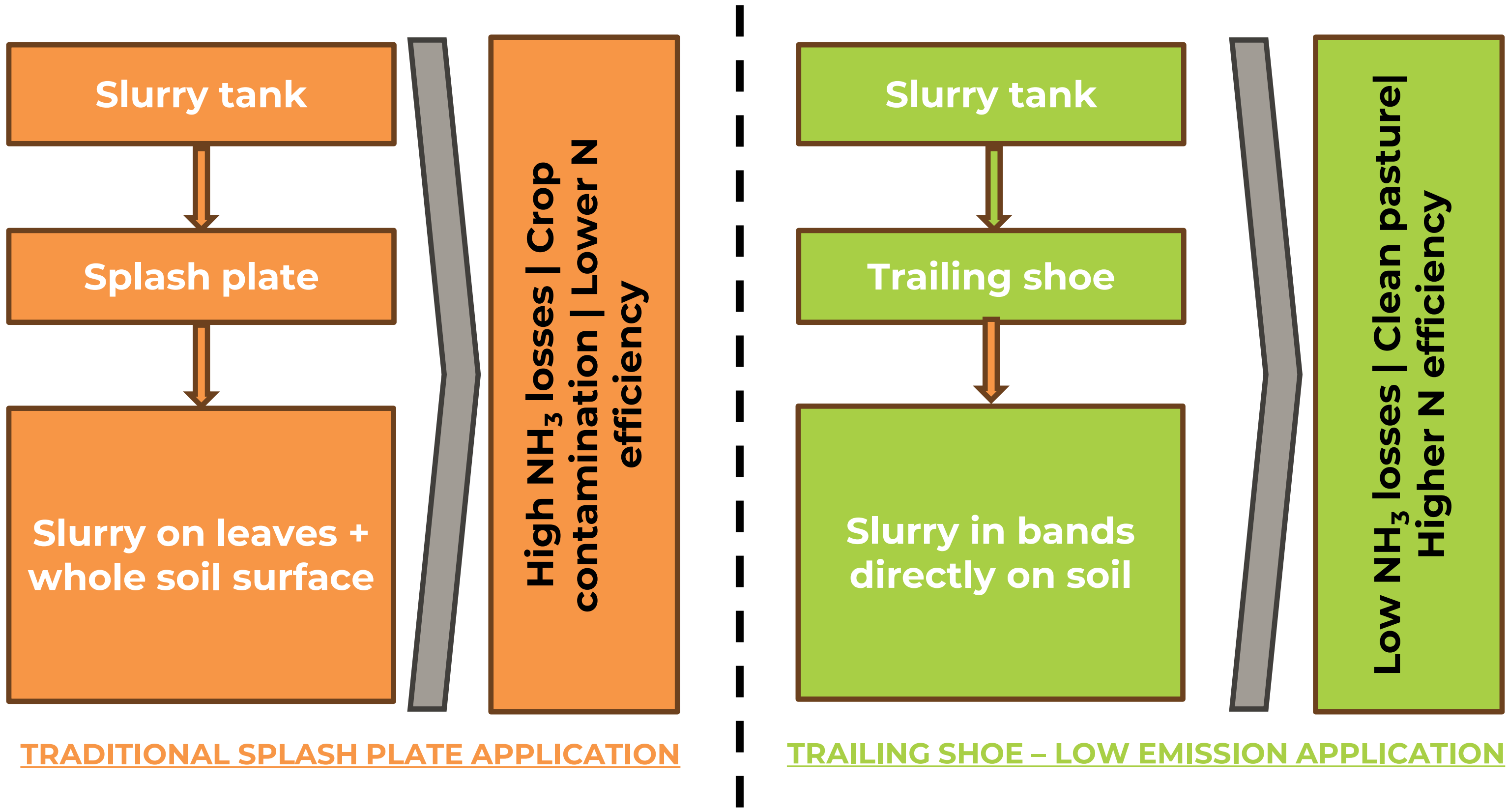
Low-emission slurry application by trailing shoe system.

State of the Art

Traditional slurry application by splash plate leads to high ammonia emissions due to the immediate exposure of slurry to air, uneven nutrient distribution and contamination of the crop canopy.
Low-emission application techniques have been developed to overcome these limitations. Among them, the trailing shoe system applies slurry directly onto the soil surface in narrow bands beneath the crop canopy, significantly reducing volatilisation losses.
This technology is increasingly adopted in grassland systems and is recognised as a best available technique (BAT) to reduce ammonia emissions while improving nutrient use efficiency.

Description of the manure management strategy/technology

The trailing shoe system places slurry on the soil surface using flexible shoes that open the crop canopy and deposit the slurry in continuous bands.
This application method reduces contact between slurry and air, improves nutrient placement near the root zone and avoids contamination of leaves, making it suitable for grassland and forage crops.



Main benefits expected

- ❖ Reduced ammonia emissions compared to splash plate application
- ❖ Improved nitrogen use efficiency and fertiliser value of slurry
- ❖ Better nutrient placement close to the soil and root zone
- ❖ Reduced crop contamination and improved forage quality
- ❖ Increased compliance with environmental regulations

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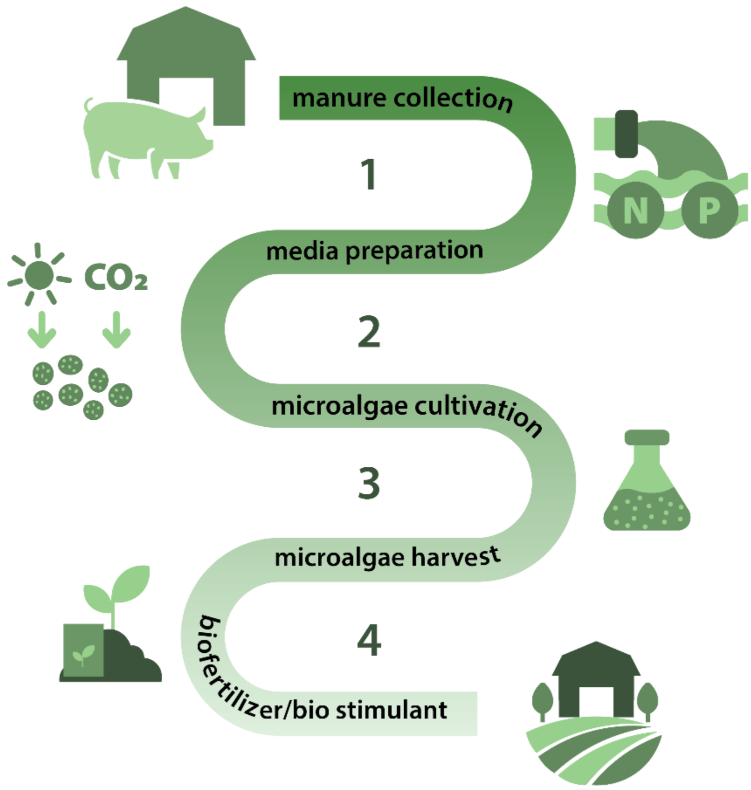
Microalgae primary treatment technology – Removal of N and P from liquid fraction of pig manure

State of the Art

Livestock effluent treatment is vital to prevent nutrient pollution, eutrophication, soil imbalance, and groundwater contamination. Microalgae cultivation using liquid fraction of pig manure offers a low-cost, nature-based solution that cleans wastewater, captures CO_2, and converts pollutants into valuable biomass. Several microalgal species, including *Chlorella vulgaris*[1] and *Scenedesmus obliquus*[2], have been shown to effectively remove nitrogen and phosphorus from manure/piggery wastewater, achieving nutrient-removal efficiencies of approximately 50% to 80% after 10 to 40 days of cultivation, depending on the species. Additionally, the algal biomass produced when applied to soils, gradually release nutrients to boost plant growth, acting as bio stimulants. Thus, algae-based systems reduce pollution, enable nutrient reuse as biofertilizers, and have the potential to create value through biomass production.

Description of the manure management strategy/technology



1. Collect and use liquid fraction of pig manure directly as a source of nutrients (N and P)
2. Microalgae remove the nutrients from the medium, up taking them into the biomass
3. Harvest and utilize microalgal biomass as biofertilizer/bio stimulant
4. Enhancement of soil health and crop growth

Main benefits expected

- **Efficient nutrient removal:** Microalgae uptake nitrogen (N) and phosphorus (P) from liquid effluents.
- **CO_2 capture and climate impact mitigation:** Microalgae cultivation consumes atmospheric CO_2, contributing to greenhouse gas emissions reduction.
- **Resource recovery and valorization:** Harvested microalgae biomass can be transformed into biofertilizers or bio stimulants, creating added value.
- **Environmentally friendly and sustainable:** No need for expensive or hazardous chemical treatments, promoting a circular economy approach.

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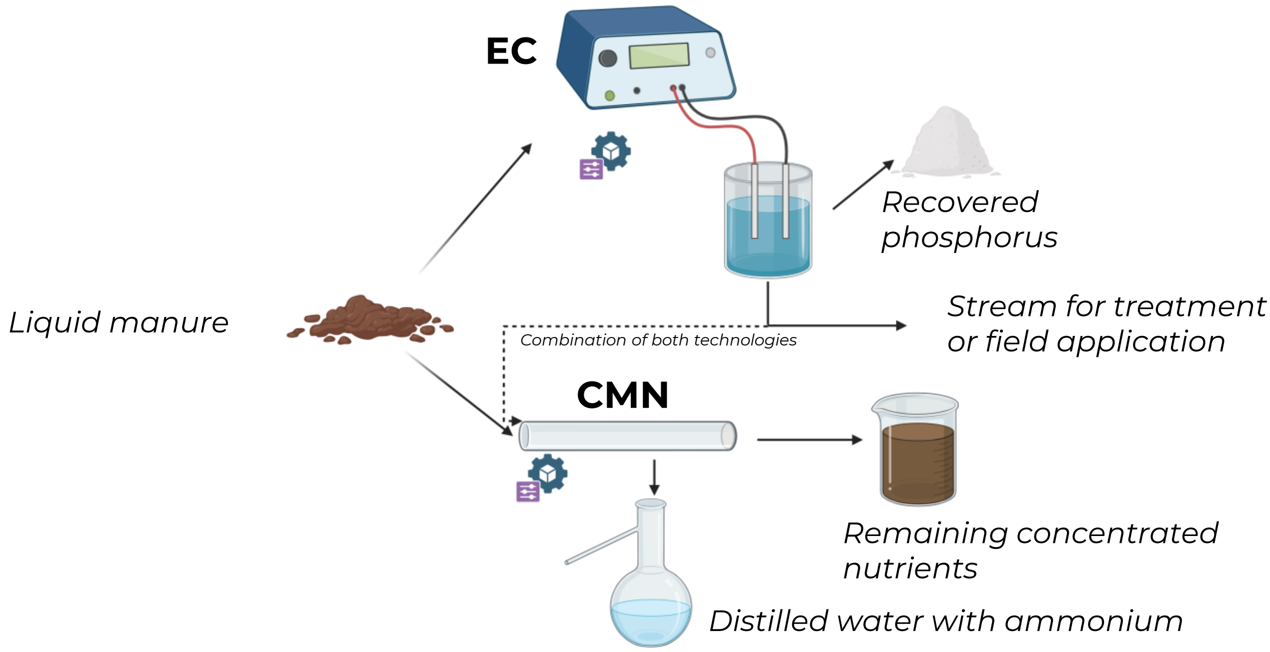
Electrocoagulation (EC) and Ceramic membrane distillation (CMN)

State of the Art

Livestock waste such as manure are rich in nutrients such as phosphorus and nitrogen, These nutrients can reach bodies of water, triggering episodes of eutrophication if not managed correctly. However, they can be recovered through physical processes such as EC or CMN. EC is used to destabilize orthophosphate loads and promote coagulation. In this way, phosphorus can be recovered through further sedimentation. On the other hand, the CMN has a dual purpose. The phosphorus and other nutrients can be concentrated by distilling the manure, but a liquid stream without solids and with a high NH4 content is also generated if the operating conditions are right. Both technologies can work separately, depending on the objective and characteristics of the stream, but combining them allows synergies to be exploited. EC removes phosphorus and particulate matter, which contributes to improving distillation rates and also facilitates control of the qualities obtained in CMN.

Description of the manure management strategy/technology

The EC process will be evaluated under different operating parameters (voltage, current intensity, pH, temperature, electrode material...) to evaluate the phosphorus recovery capacity.



The CMN will be tested with different flows, pH levels, membranes, temperatures, etc., and the filtration rate and the quality of the distillate and concentrate will be analyzed.

Main benefits expected

- Recovery of nutrients such as phosphorus and ammonium.
- Recovery yields based on operating parameters
- Identification of synergies between treatments to minimize operating costs

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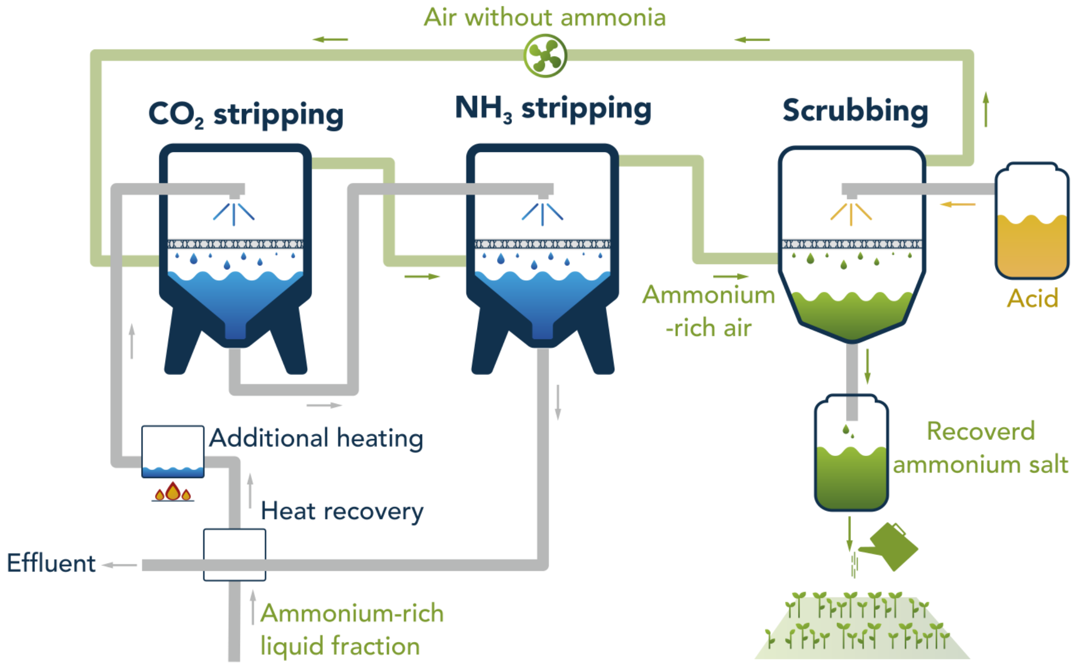
Air ammonia stripping

State of the Art

Ammonia recovery from manure is mainly based on conventional air stripping technologies. These systems typically require high energy input and the addition of caustic chemicals to increase the temperature and pH in order to promote ammonia volatilization and increase stripping efficiency. While effective and commercially available, these technologies involve significant energy use and chemical consumption, resulting in relatively high operational costs and environmental impacts.

Description of the manure management strategy/technology



Detricon's Ammonia Mining Unit (AMU) recovers ammonia from manure by combining mechanical separation, air stripping, and acid scrubbing. First, raw manure is separated into a solid and a liquid fraction. The liquid fraction is heated to reach high stripping efficiency. Heat requirement is low, however, because of the very efficient heat recovery; an increase of only 3°C is needed. In the stripping reactor, ammonia is transferred from the liquid to the air stream. Chemical consumption is low, because of CO_2 stripping that increases the pH, enabling higher ammonia stripping efficiencies. Ammonia-rich air is then treated in a scrubber, where it reacts with acid to form a recovered ammonium salt that can be used as fertilizer. Cleaned air is recirculated, while the treated liquid effluent, with most ammonia removed, can be applied on the farmland.

Main benefits expected

- Low heat requirement – only 3°C due to efficient heat exchange
- Low chemical use – CO_2 stripping often eliminates the need for caustic dosing
- High ammonia recovery efficiency – enabled by a two-stage process
- Plug-and-play design – quick and simple unit delivery
- Flexible placement – easy integration into existing facilities

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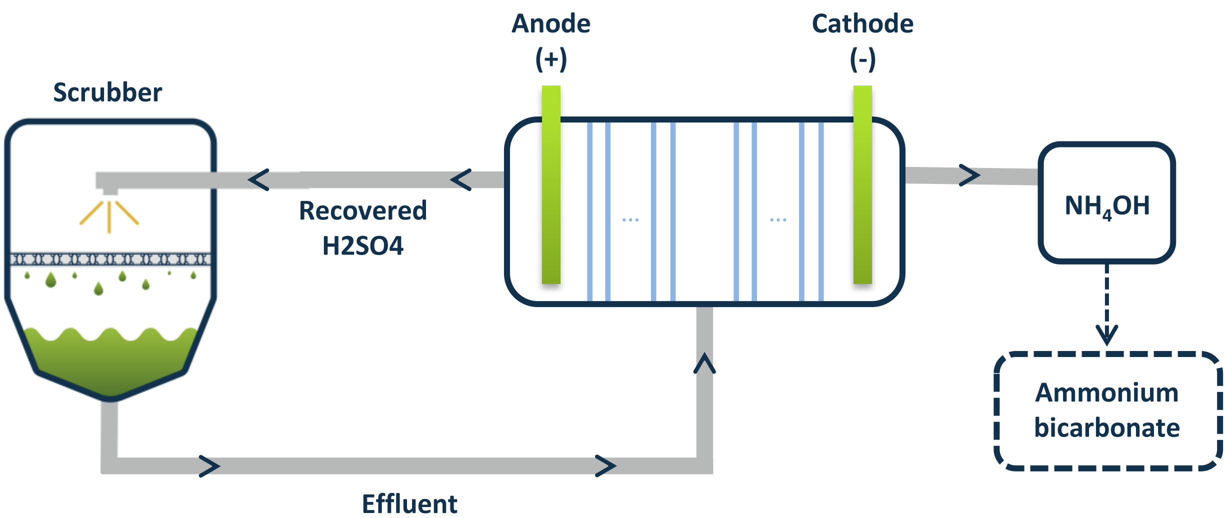
Zero-Chemical Ammonia Recovery

State of the Art

Conventional ammonia recovery is mainly based on air stripping combined with acid scrubbing, capturing ammonia from N-rich streams such as manure, digestate, and wastewater. These systems rely heavily on chemicals like sulfuric or nitric acid, which increase operational costs, handling risks, and environmental impacts. The recovered product, typically ammonium sulfate, has a low market value and cannot be classified as organic nitrogen, limiting its agricultural use. It also has low nitrogen concentration compared to other commercial products. Rising natural gas and fertilizer prices, along with stricter nitrogen regulations, have highlighted the economic and strategic drawbacks of traditional nitrogen management. These challenges emphasize the need for more sustainable, chemical-efficient, and circular nitrogen recovery technologies.

Description of the manure management strategy/technology



This technology employs an electrochemical cell to increase ammonia concentrations in streams such as recovered ammonium sulfate, while actively recovering the used acid. Under an applied electric current, ammonium ions are transported through selective membranes. At the cathode, ammonia is converted into ammonium hydroxide, while at the anode, sulfate is converted back into sulfuric acid and recycled back to the scrubber. Ammonium hydroxide has a higher market value than ammonium sulfate, can reach higher concentration, and can be further processed into ammonium bicarbonate crystals in a downstream crystallizer unit. By using electrical energy to drive selective ion transport, this process eliminates the need for chemical additives, offering a cleaner and more sustainable method for nitrogen recovery.

Main benefits expected

- Chemical-free ammonia recovery – no added acids or bases
- Higher-value products – ammonium hydroxide & ammonium bicarbonate crystals
- Sulfuric acid recycling – reduces chemical use in stripping
- Sustainable process – driven by electrical energy instead of chemicals

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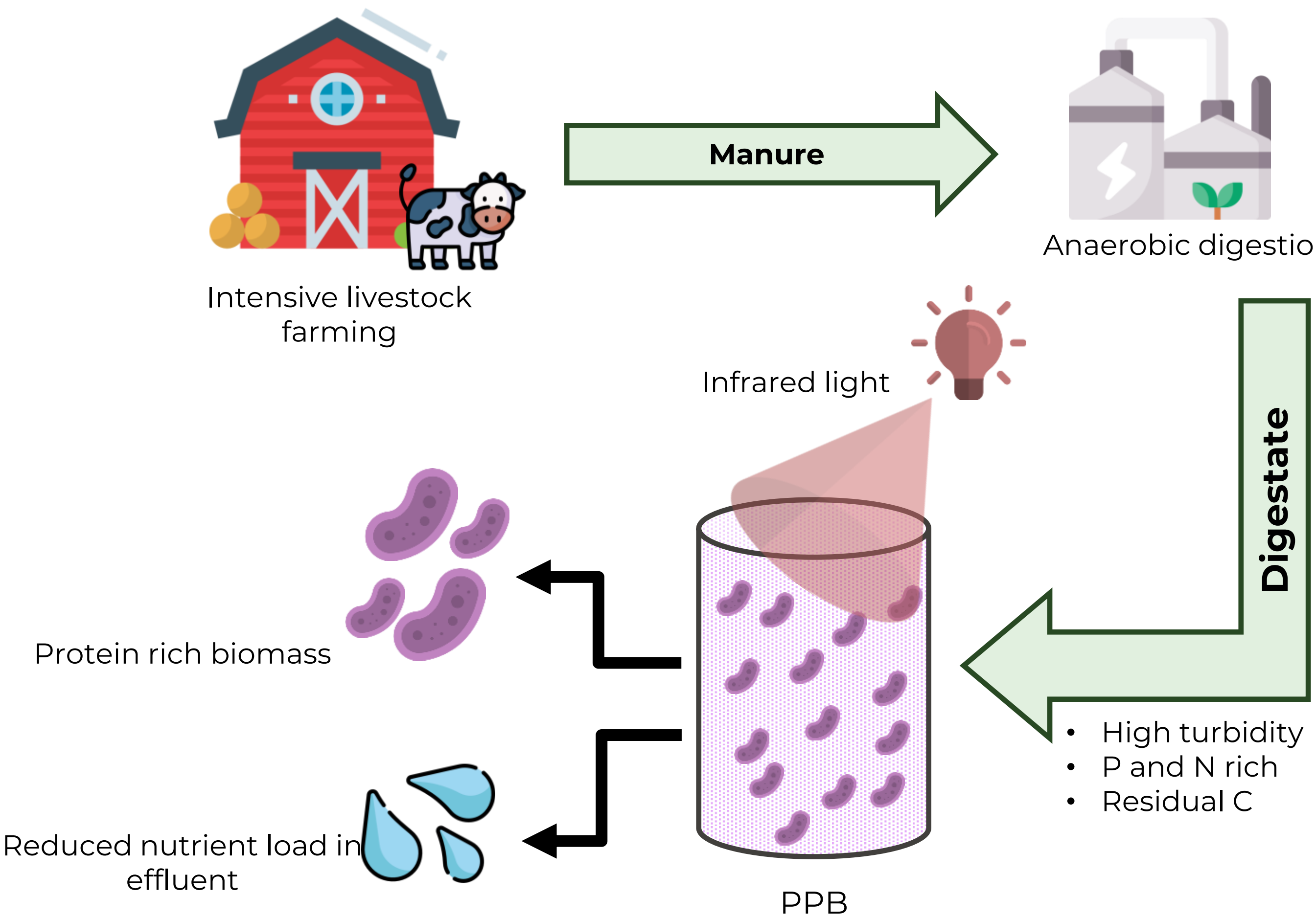
Purple Phototropic Bacteria (PPB) culture

State of the Art

Purple phototrophic bacteria (PPB)-based processes are emerging as environmentally friendly alternatives for manure treatment, as they can recover nutrients while simultaneously reducing environmental impacts. Using near-infrared illumination, PPB can convert nutrients and carbon into a protein-rich microbial biomass suitable for use as a biofertilizer. PPBs exhibit high metabolic versatility and can fix CO_2, positioning these systems as low-emission processes with potential to mitigate greenhouse gas emissions.

Light availability is a key operational parameter determining PPB performance, as the high turbidity of livestock manure digestate significantly reduces light penetration and, consequently, PPB productivity. This constraint remains one of the main challenges for application, highlighting the need for optimized reactor design and operating strategies together with the assessment of the properties (NPK content) of the produced biomass.

Description of the manure management strategy/technology



Main benefits expected

- ❖ Nutrient recovery through direct assimilation of nitrogen and phosphorus into microbial biomass for use as a fertilizer.
- ❖ Low gaseous emissions, with potential CO_2 uptake through PPB carbon fixation.
- ❖ Valorization of manure into high-value products and clean water, contributing to circular nutrient management

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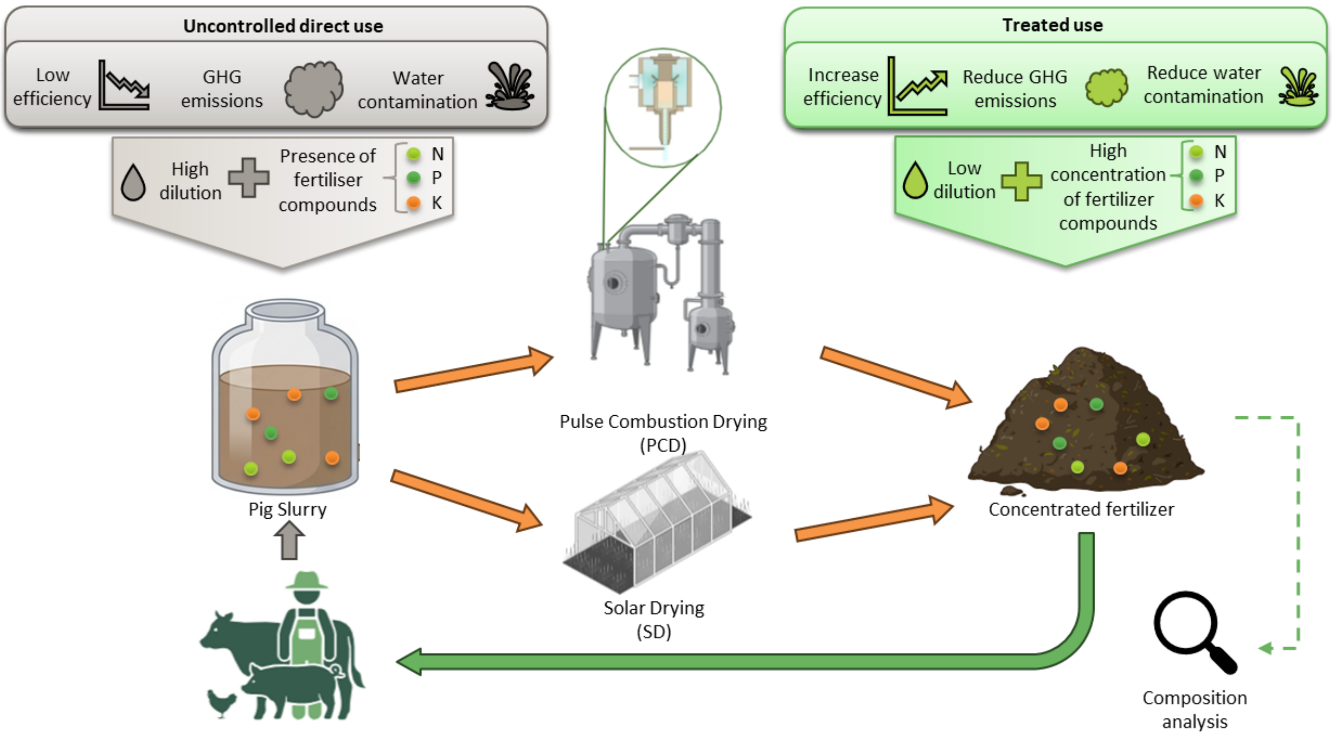
Pig manure drying technologies: Solar drying (SL) and Pulse Combustion Drying (PCD)

State of the Art

Manure management faces major challenges due to its high-water content, which increases treatment costs and leads to emissions and eutrophication when applied directly to land. Solar drying and acidification offer promising routes to reduce greenhouse gas and ammonia emissions while enabling safer, more efficient nutrient recovery for agricultural use. Pulse Combustion Drying (PCD) emerges as an intensive alternative, offering high thermal efficiency and suitability for complex substrates, though it requires process optimization and assessment of product quality, emissions, and energy use before full implementation.

Description of the manure management strategy/technology

The drying technologies will be evaluated by treating a sample of untreated pig manure. The evaluation will include energy consumption, greenhouse gas emissions, and fertilizer quality.



Main benefits expected

- Both technologies address the same core challenge: the large manure volumes generated by intensive livestock production which demand high-capacity, efficient treatment systems.
- They aim to environmental impact by stabilizing manure, limiting uncontrolled gaseous releases during handling and treatment and reducing the total volume to transport..
- Both approaches focus on concentrating manure to improve manageability, reduce transport costs, and enhance its potential for agricultural valorization.
- They are particularly relevant in high-density livestock regions with limited land availability, where more intensive manure-treatment technologies are necessary to ensure sustainable management.

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Modular vermigestion system for treating pig manure.

State of the Art

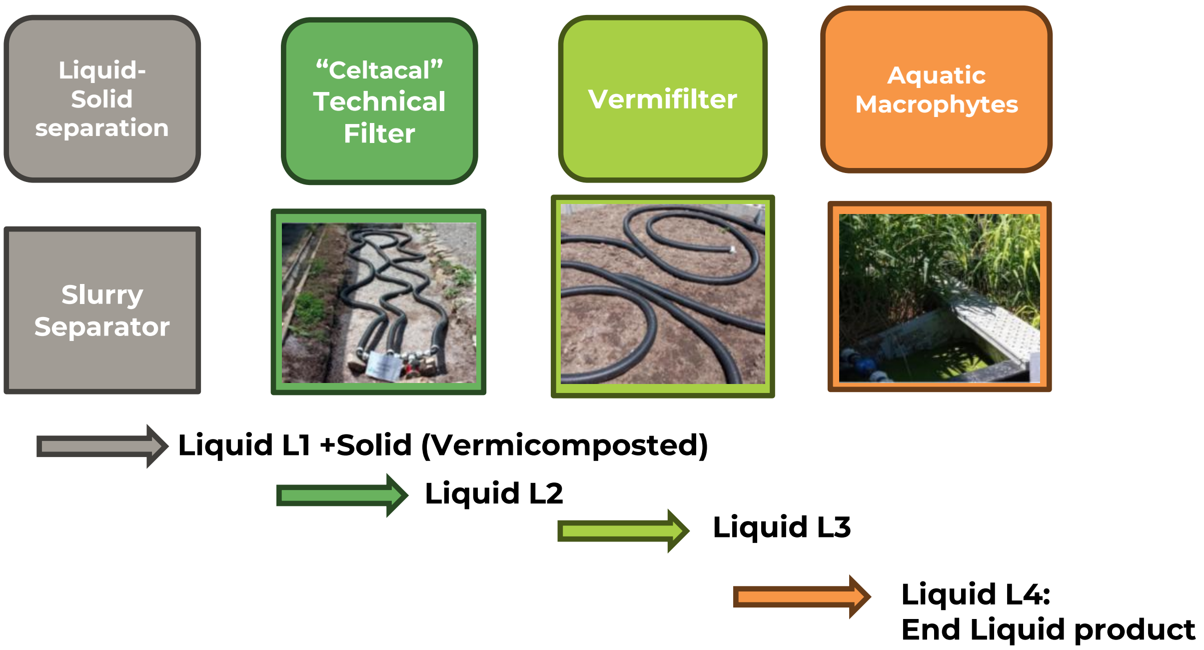
The system is composed of three interconnected modules to treat pig slurry, separating and transforming its solid and liquid components.

- Technical Filter: Solid filter composed of mollusk shells and decomposed animal manure. This filter promotes the retention of nutrients such as nitrogen and phosphorus, minimizing exposure to air and solar radiation. The resulting liquid fraction flows to the next step in the process.

- Vermifilter: The liquid passes through a vermifilter where earthworms digest and degrade the slurry. The liquid resulting from this process flows to the next step.

- Macrophyte Filter: The liquid is filtered through a system of macrophyte aquatic plants, which use the nutrients in the liquid as a food source, reducing their nutrient load.

Description of the manure management strategy/technology



Main benefits expected

- Low cost technology
- Agronomic use of liquid (L1) and solid factions. Reduce mineral fertiliser dependence.

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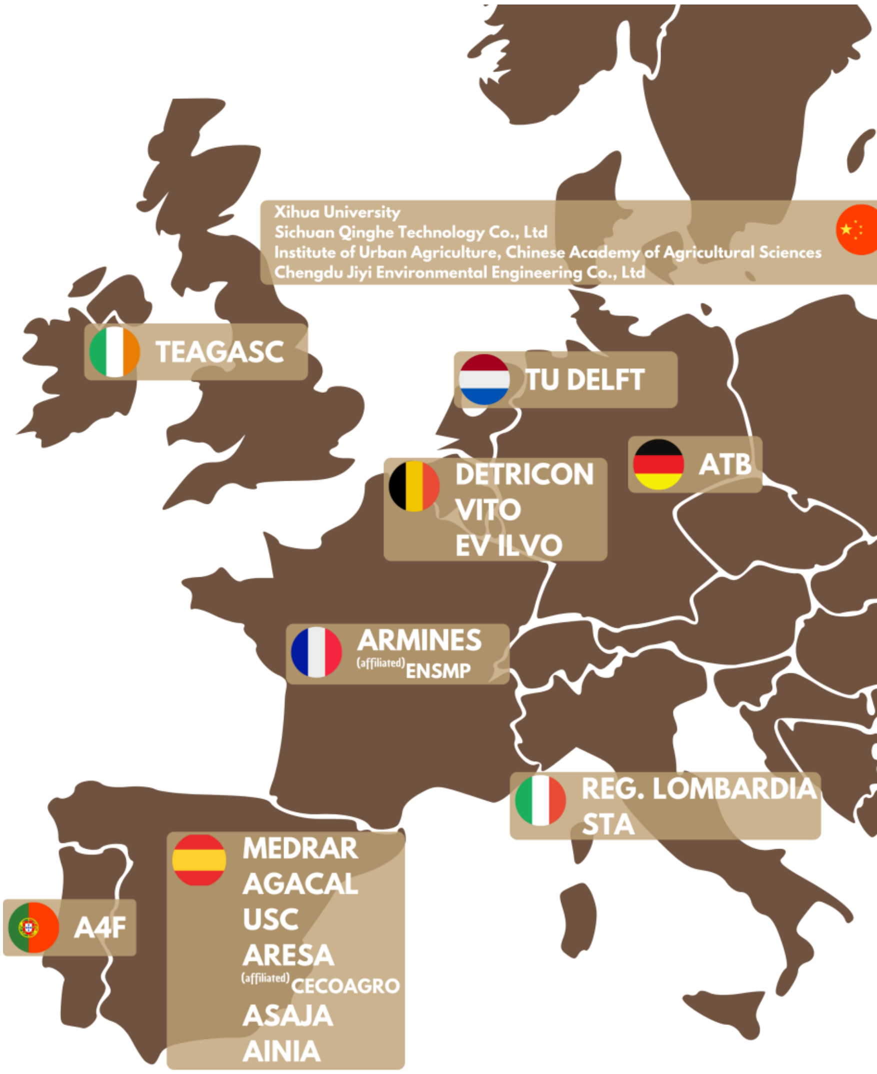
INNOVATIVE DECISION-MAKING TOOL FOR DEFINING THE MOST SUITABLE MANURE MANAGEMENT STRATEGIES TO ACHIEVE A SUSTAINABLE LIVESTOCK FARMING SYSTEM DURING THE WHOLE VALUE CHAIN



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