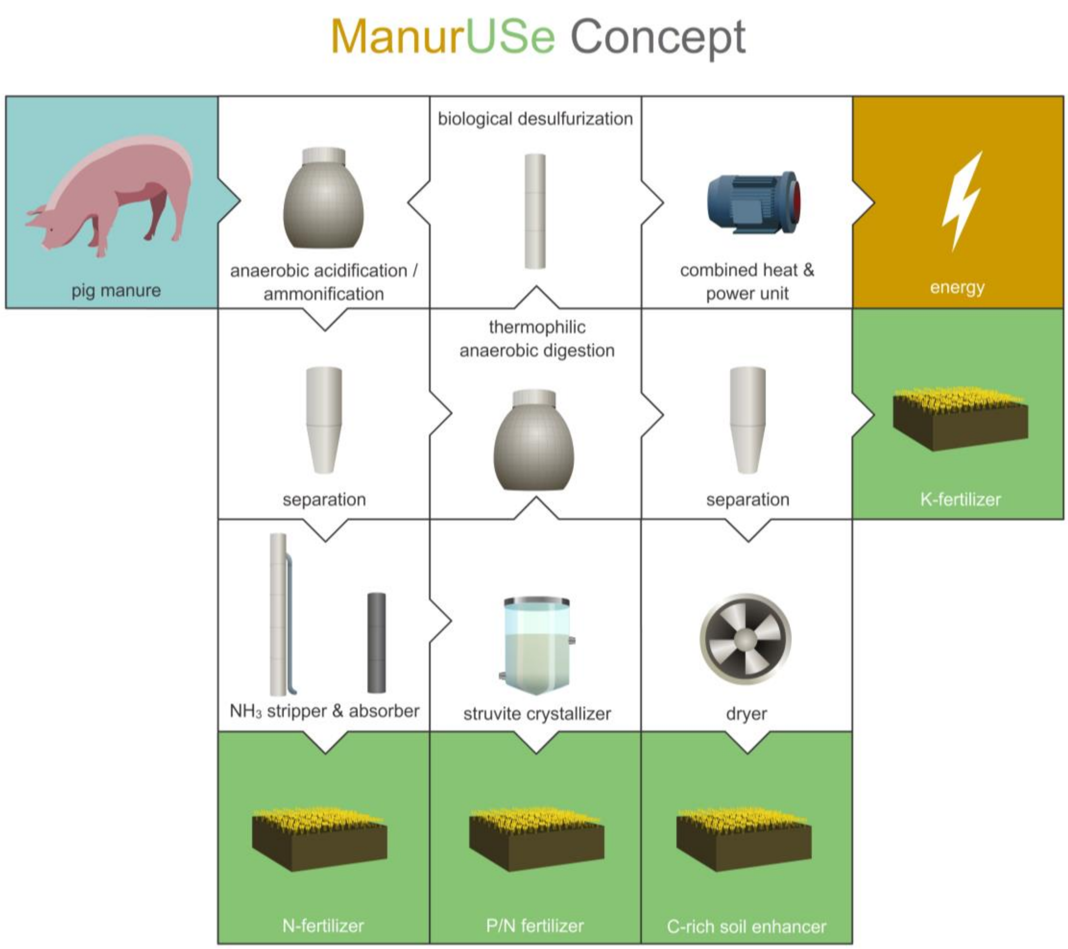
ManurUSe: manure processing for maximized nutrient recycling in US

1. *Summary*

ManurUSe is a **high-end biorefining strategy** for livestock waste recycling in US. In a flexible and modular approach, four streams are produced, each with distinct fertilization properties. Besides the high quality, safety and stability of these products, they can easily be fed into existing fertilization equipment. ManurUSe can be retrofitted into existing processing facilities, as it is based on core processes like anaerobic digestion and solid/liquid separation. The installation will **recover >66% of the nitrogen (N),** mainly as a **pure and concentrated liquid N fertilizer.** Yet, the highlight of this approach is a **>50% phosphorus (P) recovery as high-purity crystals** while avoiding the input of resources as much as possible. In recovery schemes, P is typically the compound limiting enhanced manure nutrient mining, while it is the most critical raw material among the macronutrients. Given the P recovery core, ManurUSe focuses on **medium-large facilities with hog manure effluents,** with a design example elaborated for around 13,000 hogs (50 ton manure/day). The **stable and safe organic carbon stream** will be of great local value, as it is **low in phosphorus. Overall energy autonomy** is ensured and internal looping of liquid and gaseous streams minimizes operational costs. The estimated overall cost is around **26 USD/ton manure** treated for a complete and new installation, yet a **list of cost saving opportunities** is presented for both capex and opex, as well as **increasing revenues** in the near future. The ManurUSe approach facilitates the redistribution of recovered nutrients from regions with high livestock activity as concentrated products, that can be **re-blended according to fertilization requirements** and can easily be **transported to areas which are now dependent on nutrient import.**



2. *Technology description and objectives*

2.1 Addressing the Primary Criteria and Desirable Characteristics

The proposed technology addresses both Primary Criteria required by the Nutrient Recycling Challenge:

- Recover and concentrate nutrients from manure in a usable form. ManurUSe valuable end products are **streams enriched with concentrated and separated N, P and C nutrients**, being a liquid ammonium nitrate (N), struvite crystals (P & N) and a C-rich dried solid. The proposal ensures recovery of >50% of the P, and optimization is expected to yield **as much as 75% conversion of P into crystals.** Given this goal, hog manure was chosen, as it contains the highest P levels. All types of recovered bio-based fertilizers **can be directly used by typical machines for agricultural fertilization.**
- Cost-effective manner. The integrated process is based on an **energy self-sufficient platform**: anaerobic digestion coupled with CHP guarantees the production of heat and power that is used for sustaining the units operation. In addition, **heated air recirculation and the in-situ biological production of acids** (from organics and from hydrogen sulfide) renders a very low operational cost compared to any alternative process yielding crystalline P at such high recovery yields. It is expected that the overall treatment cost can be significantly lowered below 26 USD/ton manure treated.

Moreover, the ManurUSe technology meets the additional Desirable Characteristics requirements, like:

- Ability to yield value-added co-products from the recovered nutrients.
  - NH_4NO_3 is well-known for its properties as soil fertilizer (Ahlgren et al., 2008). As NH_3 was separated over the gas phase, the recovered product is very pure.
  - Struvite is a slow release fertilizer (Tao et al., 2016), which provides crops with P and N for an extended period, maximizing nutrient usage efficiencies in the field.
  - The organic carbon (C)-rich solid fraction is an excellent **soil enhancer**, and can be valorized under all field conditions, as it is exceptionally low in P. The solid digestate undergoes a drying step that ensures sanitation and stabilization of the final C-rich product.
- Decreased moisture content. Following anaerobic digestion, the digestate is separated in liquid and solid fractions. The latter is then dried, finally obtaining **dry and sanitized pellets** (18% moist), saving a lot of costs for **safe transportation** (Arlabosse et al., 2012).
- Ability to produce low-nutrient effluent from liquid manure stream. The only liquid effluent produced in the process will have low N, P and C concentrations, and little **higher amounts of potassium (K)**, thus representing **suitable stream for crop and soil irrigation**.
- Yield multiple benefits. Besides the low opex, energy self-sufficiency (independency of fossil-fuel derived energy), and recovery of multiple clean and safe streams, the proposed system will have ultralow emissions of **greenhouse (CH_4) and acidifying (NH_3) gasses**.
- Compatibility with existing production and manure management systems. The ManurUSe system can be **retrofitted in existing facilities**, including anaerobic digesters and solid-liquid separators. As such the installation cannot be directly applied to either pre-separated manure streams (liquids vs. solids) or to digestate, yet existing process units can be re-used and integrated into the overall concept.
- Portability. Depending on the local requirements, **some process units can be omitted in the design,** e.g. solid/liquid separation, dryer or ammonia stripper/absorber. Furthermore, the **installation is flexible to direct each one of the nutrients** (P, N, K) towards two of the four output streams.
- Replicability and scalability. Starting from pilot level, the units can be **scaled up to higher processing volumes**, this is also encouraged as economies of scale come into play, and furthermore the performance of some units (e.g. solid/liquid separator and CHP) is more efficient at larger scale. The

system can be adopted also in dairy farms, yet a lower P recovery may be gained due to the lower initial content in the raw cattle manure.

- Farmer-friendliness. The final goal of the ManurUSe system is to be operated by farmers with **minimal support from engineering or consultancy companies**. The technology has an easy outline and, once at stable condition, will operate with basic operational knowledge. The **recovered products feed into conventional fertilization equipment.**

2.2 Technical information of the ManurUSe system

The ManurUSe system is schematically presented in Figure 1.

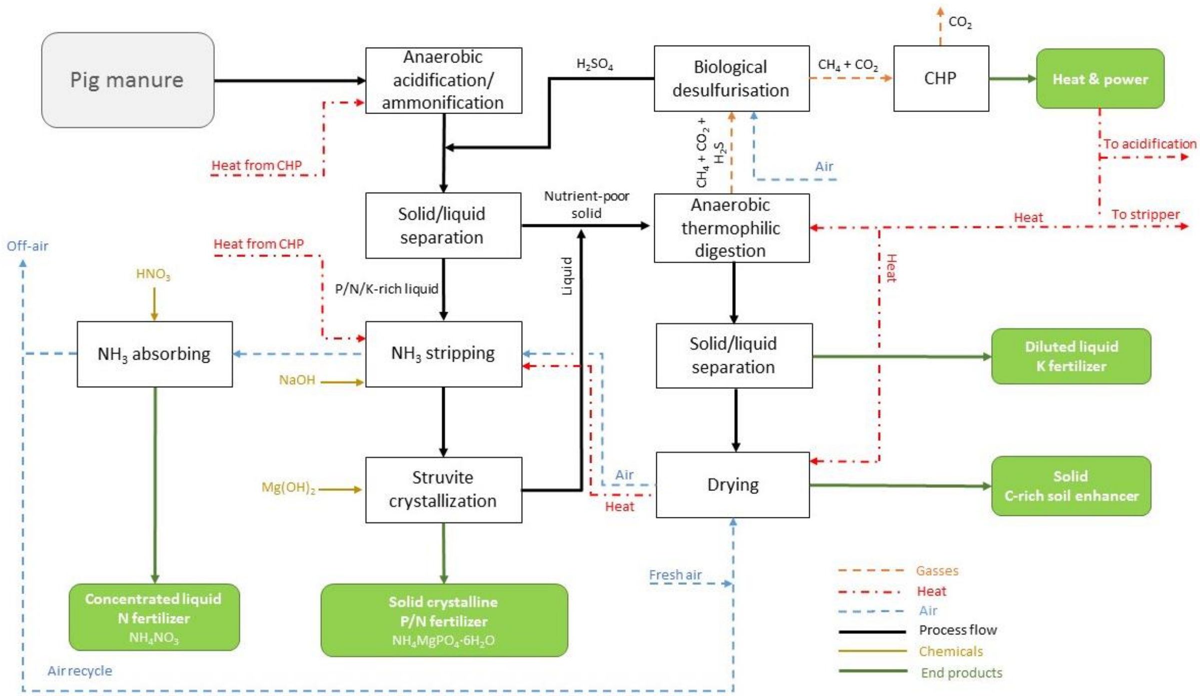


Figure 1. Scheme of the ManurUSe integrated steps

The ManurUSe system combines the following processes:

- Anaerobic acidification/ammonification (enhancing P release)
- Solid/liquid separation after addition of recovered sulfuric acid (the ‘S loop’); liquid fraction treatment:
    - Ammonia stripping and recovery
    - Struvite crystallization
- Recombination of solid fraction and liquid from the struvite unit into anaerobic digestion, with following gas valorization:
    - Biological production of sulfuric acid (the ‘S loop’, enhancing P release)
    - Combined heat and energy power (CHP)
- Solid/liquid separation of digestate:
    - Liquid fraction for soil irrigation
    - Solid fraction for drying

As hogs produce the highest P levels in manure, we worked out a case to treat 50 ton hog manure/d (corresponding to about 13,000 heads, assuming a manure production of 1.4 ton/hog head/year), loaded in a continuous way (i.e. 365 d/year). The **produced heat and energy is used on site**. The N, P and K fed are assumed around 6.8 kg/ton manure (340 kg/d), 1.8 kg/ton manure (90 kg/d) and 4.0 kg/ton manure (200 kg/d), respectively. Feeding is carried out at ambient temperature (assumed around 25^oC). All vessels (excluding the storage ones) and most piping are insulated to prevent heat dissipation.

Anaerobic acidification/ammonification

This process is carried out using a microbially catalyzed acidification and ammonification of manure under controlled conditions (37^oC), achieving i) **increased availability of organic compounds** through acidification, ii) **ammonium dissolution through ammonification, iii) ammonia emissions reduction into the environment**, thus increasing the amount on N dissolved in the manure and iv) **maximization of the P availability** through acidification. During this process, no changes occur in overall N, P and K concentrations. The heat required to operate this unit is provided by the CHP. To prevent phosphate separation from liquid in the subsequent step, the manure is further acidified after treatment using sulfuric acid. Its actual consumption is minimized thanks to the recirculation of diluted H_2SO_4 from the biogas desulfurization module (the 'S loop').

Aerobic acidification/ammonification

Parameter	Unit	Value
Effluent acidification/ammonification	ton/d	50
Organic dry matter	kg/d	3,150
Nitrogen	kg/d	340
Phosphorus	kg/d	90
Potassium	kg/d	200
Heat input	kW	29

1st solid/liquid separation

Parameter	Solid fraction		Liquid fraction	
	Unit	Value	Unit	Value
Volume	ton/d	14	ton/d	37
Nitrogen	kg/d	82	kg/d	258
Phosphorus	kg/d	45	kg/d	45

1st solid/liquid separation

The acidified manure is mechanically separated into a solid and liquid fraction without application of flocculants and/or polymers using a screw press. In a conventional approach, the P would be lost to the solid fraction. In ManurUSe however, the acidification will bring very high amounts of P in solution, thus the **resulting liquid contains the majority of N and P**, while the **organic carbon is maintained in the solid phase**. The solid fraction is directed to the anaerobic digester while the liquid one is addressed towards the ammonia stripper.

Ammonia stripping and recovery

Nitrogen is recovered from the liquid fraction through ammonia stripping and recovery. Ammonia stripping is especially designed at low temperature and pressure for this treatment process. It is a well-known technology, which uses air for the **removal of NH_3 from the liquid fraction of manure**. The following acid scrubbing process **recovers the ammonia as NH_4NO_3**, an efficient fertilizer product. The heat needed for the stripping process is delivered by the hot exhaust air from the solid digestate dryer, rendering maximum usage of the recovered energy. In the meanwhile, any NH_3 volatilization from the digestate drying is valorized as fertilizer. The rest of the required heat is provided by the CHP unit. After NH_3 recovery, some air is purged to prevent build-up of compounds such as CO_2, moreover the scrubbing air is recycled back to the digestate solid fraction dryer. Caustic soda is dosed in the stripper to maximize the ammonia recovery.

Ammonia stripping and recovery

Parameter	**Unit**	**Value**
Ammonia stripping		
Effluent ammonia stripper	ton/d	37.5
Nitrogen	kg/d	49
Phosphorus	kg/d	45
Estimated NaOH consumption (32% w/w)	m^3/d	1
Heat input required	kW	54
Ammonia recovery		
Ammonia recovered	kg N/d	209
Nitric acid consumption (68% w/w)	m^3/d	1
Ammonium nitrate solution production (52% w/w)	ton/d	2.3

Struvite crystallization

Recovery of P is carried out through crystallization of struvite ($NH_4MgPO_4 \cdot 6H_2O$), a well-known slow-release bio-based fertilizer (Kumar and Pal, 2015). **Controlled struvite crystallization allows for high purity struvite crystals** formation, meeting the requirement for farmers, but also for fertilizers producing companies for controlled, high-quality bio-based fertilizing compounds. In order to prevent concentration of chlorides in the effluent, $Mg(OH)_2$ is the preferred base to operate the struvite crystallizer. The supernatant is directed to the anaerobic digester.

Struvite crystallization

Parameter	**Unit**	**Value**
Effluent struvite precipitation	ton/d	36.0
Nitrogen	kg/d	33
Phosphorus	kg/d	3
$Mg(OH)_2$ consumption (53% w/w)	m^3/d	0.13
Struvite slurry production (15% w/w)	ton/d	2.3

Anaerobic thermophilic digestion

Parameter	**Unit**	**Value**
Effluent	ton/d	48
Nitrogen	kg/d	115
Phosphorus	kg/d	48
Potassium	kg/d	200
Biogas (55% v/v CH_4)	Nm^3/d	1,732
Heat input	kW	14

Anaerobic thermophilic digestion

Anaerobic digestion is a reliable and standardized process that enhances the conversion of nutrients into their mineral forms. In the ManurUSe system, the solid fraction and treated liquid fraction are digested. However, co-digestion is possible with agro-industrial wastes easily available in the area of application (e.g. slaughterhouse waste etc.). Operation under thermophilic conditions enables maximum biogas production, and it is feasible as no instabilities can be caused by free ammonia, which is previously stripped out. Integration of anaerobic digestion step into the ManurUSe process ensures not only the **energy autonomy** of the entire chain, but also a **reduction of the GHGs emissions into the environment**, especially methane, 25 times more potent than carbon dioxide. The required heat input to keep the reactor at around 55°C is provided by the CHP.

Biological desulfurization

Parameter	Unit	Value
Biogas in	Nm^3/d	1,732
H_2S in	ppm	2,000
H_2S out	ppm	100
Dilute sulfuric acid production	m^3/d	0.6
Air requirement	Nm^3/h	10

CHP unit

Parameter	Unit	Value
Biogas in	Nm^3/d	1,732
Electrical energy for in-situ use	kW	140
Thermal energy for in-situ heating purposes	kW	180

Biological desulfurization

To **biologically remove and recover sulfides as sulfuric acid from the biogas** produced in the anaerobic digestion step, the biological desulfurization unit is used, with only some air and some trace nutrients as input streams. This optimizes the life duration and running costs of the CHP unit. Furthermore, the recovered sulfuric acid is reused within the ManurUSe system prior to the first solid/liquid separation. This novel 'S loop' idea will lead to accumulation of S levels within the system, and in this way reinforce biological acid production. Very low maintenance costs are required and no odors are emitted.

CHP unit

The combined heat and energy power generation is commonly coupled to digesters to **generate renewable energy** via cogeneration in the form of **heat and electric power**. The generated power is sufficient to provide all electrical energy required. The heat is used to operate several modules of the ManurUSe system, i.e. dryer, digester, ammonia stripper and anaerobic acidification/ammonification. The electrical and thermal efficiencies are assumed to be 35% and 45%, respectively.

2nd solid/liquid separation

This step facilitates and **optimizes the further solid digestate drying process, reducing its operational costs, while rendering two distinct output streams**. The liquid fraction represents one of the 4 nutrient streams generated in the ManurUSe system: the high concentration of K ensures the potential fertilizing application as irrigation water. The solid fraction is addressed to the dryer and the liquid phase is used as soil irrigation water.

2nd solid liquid separation

Parameter	Solid fraction		Liquid fraction	
	Unit	Value	Unit	Value
Volume	ton/d	4.6	ton/d	43
Nitrogen	kg/d	28	kg/d	87
Phosphorus	kg/d	43	kg/d	5
Potassium	kg/d	14	kg/d	186

Solid digestate drying

Parameter	Unit	Value
Dried organic fertilizer	ton/d	1.7
Nitrogen	kg/d	28
Phosphorus	kg/d	43.0
Potassium	kg/d	14
Heat input required	kW	84

Solid digestate drying

Drying of the solid fraction of the digestate ensures i) the **reduction of water content**; ii) the **stabilization of the substrate** and iii) the **sanitation of the final product**. The removal of water leads to the reduction of the volume of the end product, which makes easier its transportation. Treating the material at high temperature (90^{o}C) promotes the hygienic requirements for application. The air required to operate the unit is provided by the NH_3 scrubber recovery module, and the resulting air is returned to the NH_3 stripping unit, thus minimizing the air inputs required for operating both processes. The heat is provided by the CHP. NH_3 released during the drying process is recovered in the ammonia recovery step.

2.3 Economic information

The table displays a rough estimate of the manure processing economics, yielding an overall net treatment cost of about **26 EUR/ton manure treated.** While this might be somewhat higher than conventional treatment technologies, there are several perspectives for a sharper price. Firstly, according to local requirements and conditions, the **capex** could be lowered: (i) some expensive units could be omitted (e.g. final solid/liquid separation stage and dryer), and (ii) re-use/retrofitting of existing infrastructure could be done. Secondly, pilot optimization and demonstration will point out whether less than 2 FTE can operate the system, lowering the **opex**. Finally, the **revenues** are expected to increase in the near future, with (i) optimization towards higher recovery of P (up to 75%), (ii) increasing prices for synthetic fertilizer, (iii) increasing electricity prices, (iv) higher appreciation of organic carbon for soils. In the common economic climate it is not realistic to expect that operating a manure processing facility will deliver a direct economic return on investment. In the ideal world, this installation has a **minimal environmental impact,** so its price should be compared to installations with similar high-end performance features, and actually the **saved emissions to the environment (externalized cost) should be accounted for financially** (e.g. carbon emission credits). Moreover, it should be taken into account that **P is a non-renewable resource on human time scale** (Van Dijk et al., 2016): it is estimated that, at this rate, the P reserves will be depleted in 50-125 years (Cordell et al., 2009; Gilbert, 2009).

		Assumptions	**USD/year**	**USD/ head/year**
Capex	4,300,000 EUR	Treatment capacity of 50 ton/d = 18,250 ton/year (13,000 hogs). Depreciated on 15 years, assuming yearly interest rate of 2%. Excluding foundation works.	**363,300**	**27.9**
Opex	Chemicals	NaOH (32% w/w/), HNO_3 (68% w/w), $Mg(OH)_2$ (53% w/w), desulphurization nutrients	238,000	18.3
	Manpower	2 FTE; 45,000 USD/FTE/year	90,000	6.9
	Electricity	Requirement: 700,000 kWh/year; is fully self-sufficient	0	0
	Analyses	Standard follow-up	16,300	1.3
	Maintenance		86,900	6.7
	Sum opex		**431,200**	**33.2**
Revenues	NH_4NO_3	52% w/w; valorized at current N fertilizer price	180,500	13.9
	Struvite	15% w/w; valorized at current P and N fertilizer price	46,900	3.6
	Solid organic C soil enhancer	82% w/w; valorized at current compost fertilizer price (dry weight)	54,700	4.2
	K-rich irrigation water	No valorization assumed	0	0
	Electricity	Surplus production of 428,300 kWh; valorized at 0.10 USD/kWh	42,700	3.3
	Sum revenues		**324,800**	**25.0**
Overall		Capex + opex - revenues	469,700	36.1

2.4 Beyond the state-of-the-art

The ManurUSe proposal integrates well-known adapted manure processing technologies in a **synergistic solution for cutting-edge, high nutrient recovery from livestock waste**. The **maximized recovery of P is the flagship of this proposal**, since P is normally bound to solids and thus driven into soil application with no dosage nor upgrading process. ManurUSe ensures a P recovery >50%, further system optimization can safely reach a 75% P recovery. At the same time, N recovery as liquid concentrated fertilizer is >66%, and process optimization will increase this percentage up to 80%. Furthermore, the production of concentrated nutrient streams through processes that lead to dramatically reduced GHG emissions constitutes another key feature of the ManurUSe system.

The **goal of ManurUSe is to efficaciously hit the fertilizer market**, proposing a resource recovery process featuring fundamental characteristics, such as i) nutrient-concentrated sources; ii) flexibility and iii) zero waste and emissions. **Bio-based fertilizers** gained a paramount attention in the last decades (Vaneeckhaute et al., 2013) **and have a tremendous market potential**, since **their production is virtually unlimited and the consequences on the environment beneficial**. Several technologies have been developed in order to extract nutrients from waste streams, yet only few have actually reached market niches. When discussing the viability of nutrient recovery, it is mandatory to assess the application potentials of the final products. **ManurUSe aims** to **fill the gap of the fertilizers companies**, providing **biobased fertilizing material with high nutrients concentration**, mainly as N- or P-rich sources. This facilitates the possibility to **dose P in soil enhancers and growing media** for fertilizing purposes. The high P content is often a drawback in agriculture, because it is usually overdosed when applying biobased fertilizers on soil (Harris et al., 2008). For this reason, separated sources of fertilizers nutrients are required, so to create **tailor-made products and actually meet the market requests**. In particular, P is a fundamental compound in fertilizing products, but it is crucial to **recover it as a separate source**, and dose it accordingly to the crops needs. To date, the **most common technologies applied for livestock treatment (composting, digestion, storage etc.) do not provide the recovery of separate nutrient streams, thus reducing the flexibility of the market uptake potential.**

Another strong point of the present proposal is the **dramatic reduction of GHGs emission**. Livestock manure management contributes for almost 10% to the US methane emission inventory (Owen and Silver, 2015). **Slurry store (or anaerobic lagoons systems)** ensures the solids breakdown and nutrients release, yet **without providing an actual nutrient recovery process**. This system does not much against GHGs emission, eventually resulting in uncontrolled release of pollutants into the environment, i.e. anaerobic lagoons are the largest source of methane in working dairies (Owen and Silver, 2015). The integrated approach proposed by **ManurUSe aims to reduce the GHGs emission up to 96%**: manure slurry acidification is proved to significantly reduce NH_3 release (Fangueiro et al., 2015) while anaerobic digestion efficiently collects and improves biogas production for the generation of heat and power via CHP.

The present ManurUSe proposal targets the **recovery of nutrients from manure in single streams and based on plug-in flexible module**, so to eventually implement or retrofit existing manure processing facilities. This will finally **render manure marketable resources**, which can be traded between intensive livestock producing to nutrient-deficient regions. Overall, **ManurUSe targets the "ZeroWaste/Emission" concept**, since all the produc streams are potentially applicable and usable for agricultural purposes, **turning manure into a golden market potential**.

3. Technology development and optimization plan

3.1 Resources, steps and timeframe

The ManurUSe concept will be first **demonstrated at pilot scale**. The technology development will possibly tackle the following steps and timeframes: operational design (1 month), detail engineering (2 months), pilot construction (6 months), pilot operation and steady-state demonstration (1.5 years) and initiation of the commercial validation (1.5-2 years). The operational design and detailed engineering will take into consideration the modular structure of the system, thus its portability and flexibility, and eventual **possibility to retrofit the modules in existing structures and facilities**, e.g. anaerobic digesters and manure separators. **Sequential construction and start-up of the pilot's units** ensure that each module is checked and operative before the following step is started. Steady state operation is a milestone for demonstrating the technology functionality and optimizing the nutrients recovery steps. Especially when operating at pilot level, several challenges may arise during the modules start-up, thus a period of 1.5 years will be dedicated to solve possible issues and **identify the optimal process parameters for manure nutrient recovery**. Once the trial pilot period is over and the operational settings fully identified and proved, the commercial validation of the ManurUSe technology is started, including economic assessment, environmental affirmation and market enquiry targeting the optimal process configuration at full scale.

3.2 Data gathering, quality assurance, analyses

At every step of the ManurUSe process validation, data will be gathered to confirm the operation safety at each level. Thanks to the experience gathered during the execution of the ManureEcoMine European project (Section 4.1), the consortium is already competent in **evaluating the quality parameters and analyses** needed for proving the manure processing technology. Analyses on the unit performances, influents and effluents, as well as quality check on the final products will be carried out along the start-up, technological optimization and demonstration phases. Moreover, assessment of associated risks of target substances relevant for the application of the end-products will ensure that the technology will meet its goals in a safe and controlled way.

3.3 An eye to the future

Considering the expertise of the partners involved in the ManurUSe proposal, we aim to **reach final and definitive results within 2 years** from the start of the project. The proposed technology will then be ready for starting the commercial validation on large scale, with reliable data gathered from the pilot operation being the milestones for achieving a wider and more solid application and reach the final stakeholders and markets.

4. About us: introducing the consortium

4.1 Team and proposal background

The ManurUSe is proposed by the core technology partners engaged in the 3-year **project "ManureEcoMine"** (www.manureecomine.eu), financed by the European Commission (7th Framework Programme), that engages a strong and **multidisciplinary consortium** of 11 partners (among which **6 companies)** located in so-called Nitrate Vulnerable Zones, where surface and ground water eutrophication poses an environmental threat due to intensive animal husbandry. ManureEcoMine aims to process hog and cow manure in a **resource-efficient sustainability vision,** thus maximizing the recovery of concentrated N, P and K bio-based fertilizers, blended and validated for crop growth stimulation, with a pivotal attention to **economic viability**. The ManureEcoMine pilot successfully operated in The Netherlands (mainly on hog manure), and is currently under start-up in Spain (mainly on cow manure). An explanatory video clarifies the novel approach used in ManureEcoMine (www.youtube.com/watch?v=8WXdPCxCFpY).

In this ManurUSe proposal, the technological knowhow and experience of the ManureEcoMine partners are culminated in a **new and effective solution: successful choices were kept** (e.g. anaerobic treatment, struvite, ammonia stripping) and **challenges were turned into new solutions** (e.g. the need to enhance phosphorus dissolution prior to precipitation).

4.2 Consortium

Prof. Vlaeminck (University of Antwerp – Ghent University) is the ManureEcoMine coordinator, and **dr. Pintucci** (Ghent University) is the daily project manager, jointly they form the **academic lead partner** in ManurUSe. Prof. Vlaeminck is **specialized in environmental technology for nutrient management**, he is a committee board member of the Specialist Group **Nutrient Removal and Recovery (IWA)**. His connection with the nutrient challenges in the USA is extended through ongoing PhD projects (**DC Water,** prof. Chandran-**Columbia University**, prof. Sturm-**Kansas University**). The University of Antwerp (Belgium) is an excellent university which ranked 14th in the **"Top 50 Universities Under 50 years"** in 2014. In 2015, prof. Vlaeminck joined the Research Group of Sustainable Energy, Air and Water Technology, established by Prof. Lenaerts. The Laboratory for Microbial Ecology and Technology (LabMET, Belgium) is part of Ghent University, it has over **35 years of expertise** as top performing laboratory, which led to the creation of **7 spin-off companies. Prof. Rabaey** is heading the lab, with strong focus towards resource recovery from waste streams**.**

Joop Colsen, founder of Colsen Adviesbureau voor Milieutechniek BV (The Netherlands), and **Merijn Picavet,** chief technology developer at the company, jointly represent the **industrial lead partner** in ManurUSe. Established in 1989, Colsen has designed, built and operated numerous **pilot and demonstration plants for demonstrating technological breakthroughs** for biological desulfurization, (manure) digestion, wastewater treatment systems and nutrient recovery. Colsen has an excellent track record in **energy and nutrient recovery from waste and industrial or communal wastewater**, and owns a number of technologies (NAS® for nitrogen removal, ANPHOS® for phosphorus recovery, AMFER® for nitrogen recovery, Bidox® for biological desulfurization of biogas), developed in close collaboration with academia. Colsen operates worldwide (USA, China, UK, Spain, Italy and South Africa), important projects within nutrient recovery are the thermophilic digestion plant (Ecofuels) and EC sponsored projects (PigMan, ManureEcoMine).

Dr Colprim (LEQUIA, University of Girona, Spain) focuses on **nutrients removal and recovery from urban and industrial wastewaters by innovative biological and bio-electrochemical systems**. He is the principal investigator of TreatRec (EU network) and leads several technology transfer contracts on wastewater treatment and resource recovery. Founded in 1992, LEQUIA is devoted to the **development of eco-innovative water solutions**, it collaborates with Prof. Rosso (University of California-Irvine), Illinois Institute of Technology, and Prof. Chandran (Columbia University). LEQUIA's pilot scale technologies translate into scale-up, industrial implementation, registered technologies (i.e. PANAMMOX®, Smart-airMBR®) and **spin-off companies**.

The **Group of Environmental Engineering and Bioprocesses** (Biogroup, University of Santiago de Compostela, Spain), has over 25 year-experience on **treatment and management of agro-industrial wastes** with **nutrient removal and recovery**. It is recognized as **Competitive Reference Group** and several technologies have been implemented at **pilot- and industrial scale** through collaborations with companies. **Prof. Lema** is heading the group with a background on waste treatment technologies, focusing on technology, modeling and control. **Ass. Prof. Carballa** is specialized in technology and microbiology of anaerobic processes. Collaborations with the US include **Cornell University, The State of University of New York** (Buffalo) and **The University of Arizona**.

The **Institute for Environmental Biotechnology** (University of Natural Resources and Applied Sciences Vienna, Austria) aims at the exploitation of the microbial metabolism to safeguard life quality and preserve natural resources, identifying the **best possible utilization of existing resources by establishment of sustainable material cycles**. **Prof. Fuchs** is vice head of the institute, he is key researcher in the Austrian Competence center "Bioenergy 2020+", focusing on the **innovative biological and technological technologies**, mainly on digestate treatment. Prof. Fuchs has ample experience on pilot studies, e.g. ENERDEC – Nutrient recovery for the production of a high value fertilizer in organic waste treatment).

Established in 1998, **Ahidra, agua y energía S.L.** (Barcelona, Spain) is an SME expanding its activities into South America (Mexico, Colombia, Brazil, Argentina, Chile, Cuba), together with Colsen. The activities are focused on **three main fields**: (i) **Thermophilic anaerobic digestion** of organic wastes, (ii) **Industrial wastewater treatment and reuse,** i.e. high P and N effluents (e.g. manure) and (iii) **Gas/air treatment of pollutants** through trickling biofilters. Its main expertise is **building and operating pilot installations**, focusing on unique niche market insight into **N and P removal** from wastewater. **Oscar Benito** (partner and technical manager) has 20 years of experience in industrial and urban wastewater and waste treatment plants design and construction.

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