



BIOMETA
Finland

Towards economically and environmentally sustainable agriculture

A novel biomass processing innovation for dairy and swine farms



Abstract

This white paper aims to present Biometa Finland's novel biomass processing innovation, the bioproduct plant. The innovation is described comprehensively through economic, environmental, and technical lenses.

First, the current economic, environmental and technical challenges caused by the lack of manure processing in agriculture are reviewed and analysed. The paper then moves on to an analysis of the bioproduct plant's role in solving these global agricultural challenges. The bioproduct plant's placement in the small to medium-sized dairy cow and swine farm segment is also reviewed and justified.

This white paper explains the multiple benefits the bioproduct plant can provide for the farmer, for the environment and for the company offering the solution. By providing these benefits, not only could agriculture's self-sufficiency and profitability challenges be tackled, but the environmental burden could also be reduced while a significant market potential in agricultural farms could be untapped.

In addition, this white paper offers an overview of the company's research history, including the core projects in which the bioproduct plant concept was fully developed. The history section also covers the other main results of the research and developmental work over the years.

The main purpose of this white paper is to present the innovation of the bioproduct plant, its technology, uniqueness and placement in the current market sector. The aim is to ultimately realize the potential of this innovation and invite any interested parties to negotiate about the innovation.



Foreword

From the CEO

"This white paper has been a great journey down memory lane. In this paper, the entire history of Biometa Finland and its product development phases are reviewed and wrapped up into one document. The bioproduct plant innovation is truly one-of-a-kind in the current market and solutions like this are needed in agriculture's green transition.

For this white paper, I express a special thank you to Mika and Kalle and to all the others who helped in preparing and writing this paper. Mika's advice and Kalle's writing have greatly contributed to the final version of this paper and their contributions should not go unnoticed.

I sincerely hope that this white paper will lead to the harnessing of this innovation's full potential. By describing our innovation and the story behind it, we want to do whatever's necessary to bring this innovation to light and put it at the disposal of agricultural farms. We want this innovation to be one solution in helping to solve climate change and aid individual farmers facing economic challenges."

27th of April 2023, Oulu, Finland



Jari Karvonen

CEO of Biometa Finland Ltd.

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1. Introduction

This white paper presents Biometa Finland's innovation – the bioproduct plant – and its contribution to mitigating agriculture's economic, environmental and technical challenges, all mainly caused by the lack of manure handling. In the EU, currently less than 10% of agricultural manure is treated¹, leading to multiple future challenges – economic, environmental, and technical - if not addressed properly.

The bioproduct plant is primarily designed for small and medium-sized dairy farms to process manure efficiently into several valuable bioproducts. Biometa Finland's bioproduct plant is pioneering the first-in-the-world twin-bioreactor technology, named hybrid expanded granular sludge bed (HEGSB) reactors. This technology has been developed to maximize process efficiency and significantly reduce reactor size while reducing the harmful environmental effects of manure.

The purpose of this white paper is to elaborate, explain and demystify the concept of a bioproduct plant. Everything possible is being done to realize the potential of this innovation by

- offering access to this innovation to any interested parties who have the ability and willingness to commercialize it
- providing Biometa's technical and commercial information and support to build the world's first farm-scale bioproduct plant.

The innovation presented in this white paper has recently received the Seal of Excellence from Horizon Europe's EU EIC Accelerator Programme (Figure 1). This is a testament of the strength of the innovation as well as excellent project planning in terms of business modelling, commercialization preparation as well as final productization execution.



- EIC Accelerator Challenge
- Challenge: Technologies for 'Fit for 55'
- Full-scale demonstration project plan
- High quality plan
- Quality certificate
- Awarded 10/2022

Figure 1. Biometa Finland's Seal of Excellence from the EU EIC Accelerator.

This white paper starts by addressing agriculture's current challenges and provides an argument as to why there is a clear need for solutions like the bioproduct plant. After that, the paper briefly presents current biogas solutions and the most common technologies in the market now. After background and motivation, the bioproduct plant concept is discussed. The innovation is described thoroughly starting from the reactor technology, ending with integrated sub-processes and the potential suitability of the technology for different types of biomass and farms.

This paper also goes through the history of the company behind the innovation, including all the projects and technological steps throughout the product development. Finally, the paper justifies the demand for this innovation through economic and environmental lenses and presents a plan for the next steps in the final productization and commercialization.



2. Current Challenges in Agriculture

Agriculture is facing significant challenges today. The EU dairy sector outputs 1400 Mt of manure annually; however, currently only under 10% is processed in some way¹. This leads to a significant economic loss and environmental challenge, as manure can be turned into monetary products and handling it can reduce the environmental burden.

Due to rising costs and lack of self-sufficiency, farms today are struggling financially while being pushed to reduce manure-related emissions. Current solutions, namely conventional biogas plants, are too large and costly for small and medium sized farms – here referring to farms with 50–200 head of cattle – which account for 75% of the farms in the EU.

The main challenges caused by the lack of manure handling in the agricultural sector today are therefore three-fold: economic, environmental and technical – or more specifically the lack of suitable solutions for the small and medium sized farm segment.

Economic challenges

The economic challenges arise from the rising costs of different inputs, such as energy, fertilizers and bedding. All of these decrease the profitability of agricultural entrepreneurs and might reduce the number of smaller farms. Reducing the number of farms would also weaken the self-sufficiency of individual countries and therefore the security of supply and resiliency together with the ability to respond to different crises.

Processing manure on the farm is address this challenge specifically, as it can provide monetary benefits for the farm and improve the farm's profitability and self-sufficiency. Solutions that are economically viable for the small and medium-sized farms and can ultimately increase the profitability and self-sufficiency of individual farms are needed in this industry sector.

Environmental challenges

The lack of manure processing generally leads to multiple environmental challenges in the agricultural sector today.

One environmental challenge arises from the emissions caused by agriculture. Today, agriculture emits 10% of all the greenhouse gas (GHG) emissions in the EU². Farms must reduce their GHG emissions by 2030³ to meet binding national targets and EU regulatory requirements. Regarding regulatory requirements, methane emissions might soon face



regulatory reduction targets following new UN agreements⁴. Ammonia emission regulations are also taking shape in Europe and may force farms to downsize, as in the Netherlands already⁵. The global trend of reducing emissions and fighting climate change requires agriculture – and specifically small and medium-sized farms – to find solutions that can decrease emissions.

The decreasing amount of agricultural land per capita poses another environmental challenge in agriculture worldwide. Rapid population growth globally means a growing need for food production which in turn adds pressure to increase the amount of agricultural land. Globally, most of the agricultural land is being used to grow food for livestock. However, only 25% is reserved for growing food specifically for humans⁶. Currently, the way to obtain more agricultural land is deforestation, which is highly controversial when fighting climate change and biodiversity loss. Consequently, other solutions that can increase crop yields from existing fields are desperately needed.

The lack of manure processing leads to untreated manure being applied to the fields, which is a suboptimal way to fertilize fields, increase crop yield and reuse nutrients. It can ultimately lead to eutrophication and run-off to nearby waterways. This harms the environment and can create further challenges in environmental protection.

Processing and handling manure on farms locally could respond to the challenge in agriculture of targeting fertilizers. Fertilizers that are plentiful in one place are often desperately needed in another place. By producing fertilizers organically and locally from manure, fertilizing challenges could be tackled by transporting the fertilizer to the places that need it.

This is especially the case with phosphorus fertilizers. By processing manure on-farm and refining the raw material into fertilizer, new markets could be created, and the nutrient challenge could be solved in areas that need phosphorus fertilizers. Reusing nutrients efficiently and optimally is crucial in solving both fertilizing and environmental challenges.

Technical challenges

The lack of suitable solutions for the small and medium sized farm segment means that a large part of dairy farms goes unnoticed in the market. The small and medium sized farms accounts for 75% of them in the 50–200 head segment at the EU. This is a large, mainly pristine market segment that does not have a fully suitable solution for full processing of manure at a farm. Creating a solution for this segment is crucial in solving economic and environmental challenges as well.



The lack of suitable manure processing solutions is mainly due to the capital outlay and operating costs that are too large compared to the benefits gained. Solutions for the bigger farm segment often focus mainly on producing biogas, which can be profitable on a larger, more centralized scale but is rarely economically viable on smaller-scale farms. Having a solution for this market segment would increase the profitability and overall self-sufficiency of the small and medium sized farms, and ultimately bring agricultural emissions down while solving other environmental issues as well.

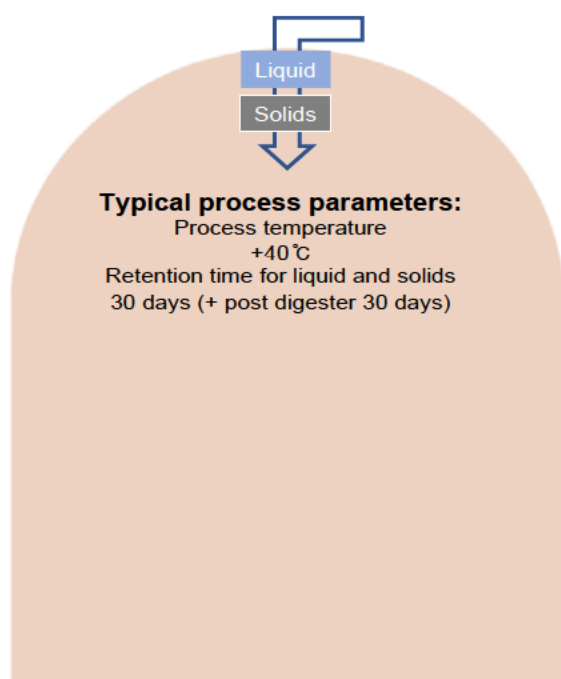
All-in-all, agriculture is facing multiple challenges today. These include economic, environmental, and technical challenges. Solutions for the bigger farm segment already exist but alone they are unable to help the agricultural sector to achieve the level of GHG and pollution reductions required by the EU, UN, and national regulation. A solution for the small and medium sized farm segment is needed to tackle the challenges comprehensively and successfully.



3. State of the Art in Biogas Technology

Current solutions in manure processing and the biogas industry consist of conventional biogas plants, focusing on biogas production. Biogas solutions in dairy farms involve using different methods to convert manure and other organic materials into biogas, which can then be used as a renewable energy source. In addition to cow manure on dairy farms, biogas can be produced from a variety of sources, for example, food waste and crop residues.

In a dairy farm, biogas production typically involves collecting the manure and mixing it with other organic materials, such as food waste or crop residues, to create a feedstock. This process where additional feedstocks are added besides manure is called co-digestion. Manure can also be used in the process as the only feedstock. The process is then called mono-digestion.



In biogas production, the feedstock is fed to an anaerobic digester (Figure 2), which is a sealed and airtight container that allows microorganisms to break down the organic material and to produce biogas. This is the most common method of producing biogas on dairy farms. In general, it involves breaking down organic matter by methanogens in the absence of oxygen.

The biogas produced can be used in many ways, such as in generation of electricity, heat or fueling farm equipment. In some cases, excess biogas can be sold to the gas grid.

Figure 2. Conventional biogas reactor and technology.

Biogas can also be upgraded. This means removing impurities and carbon dioxide from it to produce biomethane, which can then be used for a variety of purposes, such as transportation fuel.

In addition to renewable energy production, biogas solutions in dairy farms also offer other benefits. For example, the anaerobic digestion process can help reduce odour and



pathogens in the manure, making it easier to manage and handle. The process can also produce nutrient-rich fertilizers that can be used to improve soil health and crop yields.

3.1. Technologies in Biogas Production

The most common technology used for processing manure and biogas production is the continuous stirred-tank reactor (CSTR). This technology is mostly used to handle slurries with a solids content of 5–10%. CSTRs are typically applied to process slurries of animal manure and organic industrial waste.

In CSTRs, liquids and solids are typically processed in a single reactor. However, solids and liquids have different anaerobic digestion requirements, and this type of combined digestion principle is therefore challenging to optimize in terms of process efficiency.

CSTRs are low-rate digesters and are appealing because the design is rather simple and easily recognizable. The drawback might be that an extended retention time is required to keep the manure in the reactor. In summary, the typical features of conventional biogas technology include:

- Widely used: Continuous Stirred-Tank Reactor (CSTR)
- Solids and liquid are digested simultaneously in the same process
- Steel or concrete is widely used in reactor manufacturing.

In addition to CSTR, some other technologies, although few, are emerging in the market for manure treatment at farms.

High-rate technologies typically feature longer retention time of solids in the digester, resulting in higher throughput and fermentation efficiency. The emerging technologies in manure processing include fixed-film, fluidized bed (FB), up-flow anaerobic sludge blanket (UASB), internal circulation (IC), expanded granular sludge bed (EGSB) and induced blanket (IB) bioreactor types. Typically, the high-rate bioreactor designs are tailored for the anaerobic digestion of low solids concentration, utilized for example in wastewater treatment.

In the case of conventional biogas production technologies, traditional additional feeds, such as grass or maize are often used to boost biomethane production. The downside of additional feed usage may be a longer retention time in the reactors to prevent residual methane emissions from digested effluent. This can mean physically a larger reactor size and/or building a possibly costly post-digester.



3.2. Technological Suitability

Current manure processing and biogas plant solutions in the dairy sector are intended for larger farms, namely those with over 200 head of cattle. These solutions often focus solely on biogas production and utilizing it either on-farm or outside the farm.

Most of the current solutions utilize additional feedstock, such as crop residues in the process in addition to manure, so they are suitable for all types of agricultural farms. The suitability of current technologies for small and medium sized farms is, however, challenging. Higher investment costs for conventional biogas plants often make them available only to the bigger farm segment.

The high investment costs of current biogas plants are related to the size of the large reactor, which is the most expensive component of the plant. A large reactor size is required in a conventional biogas plant to achieve long retention time for the feedstock. Adding extra feedstock into the reactor to maximize the biomethane production further prolongs the retention time with conventional technologies. This being the case, for small and medium sized farms, current solutions in the market often mean higher investment costs and a longer investment payback period.

This is related to the current challenge of biogas production in agriculture. Producing biogas is highly dependent on economies of scale – which is why most of the time production of biogas alone is economically viable only for bigger farms. Usually in bigger farms, biogas can also be utilized outside the farm, for example by upgrading it for fuel use or feeding it into the grid.



4. Bioproduct Plant

Biometa's innovation is the bioproduct plant. The bioproduct plant that efficiently processes farm manure and turns it into four valuable bioproducts: biogas, liquid fertilizer, dry fertilizer and sterilized bedding. The bioproduct plant is a novel process innovation with multiple integrated sub-processes.

Through the production of bioproducts, a bioproduct plant improves the farm's profitability and self-sufficiency, while cleaning the environment by reducing manure-induced emissions, chemical oxygen demand (COD) and ammonia gas emissions. At the same time, this process enhances the fertilizer properties of the liquid and solids manure fractions. It is designed for the farm segment with 50–500 heads of cattle.

The bioproduct plant is a local, farm-specific solution to mitigate the global challenges of agriculture.

4.1. Technology

Core Process

The technology of the bioproduct plant is novel in the market. The backbone of this process innovation (Figure 3) is the breakthrough bioreactor technology, called hybrid expanded granular sludge bed (HEGSB) reactors. Whereas conventional solutions handle the manure in a single, large reactor requiring a post-digester for high methane yield, the bioproduct plant handles both the liquid and solids of the manure separately. This is done to maximize the fermentation efficiency and reduce the reactor volume to bring down costs and to prevent harmful emissions.

The bioproduct plant uniquely features the separation of manure into two bioreactors for the anaerobic digestion of liquid and solid fractions. This reduces the hydraulic retention time of liquid manure to 7 days instead of the 60 days typically needed and that of solids to 20 days instead of the typically required 60–100 days. This efficient process fully exploits the biomethane potential of the manure without further need for post- or co-digestion, while minimizing the organics and residual methane in the digestate.



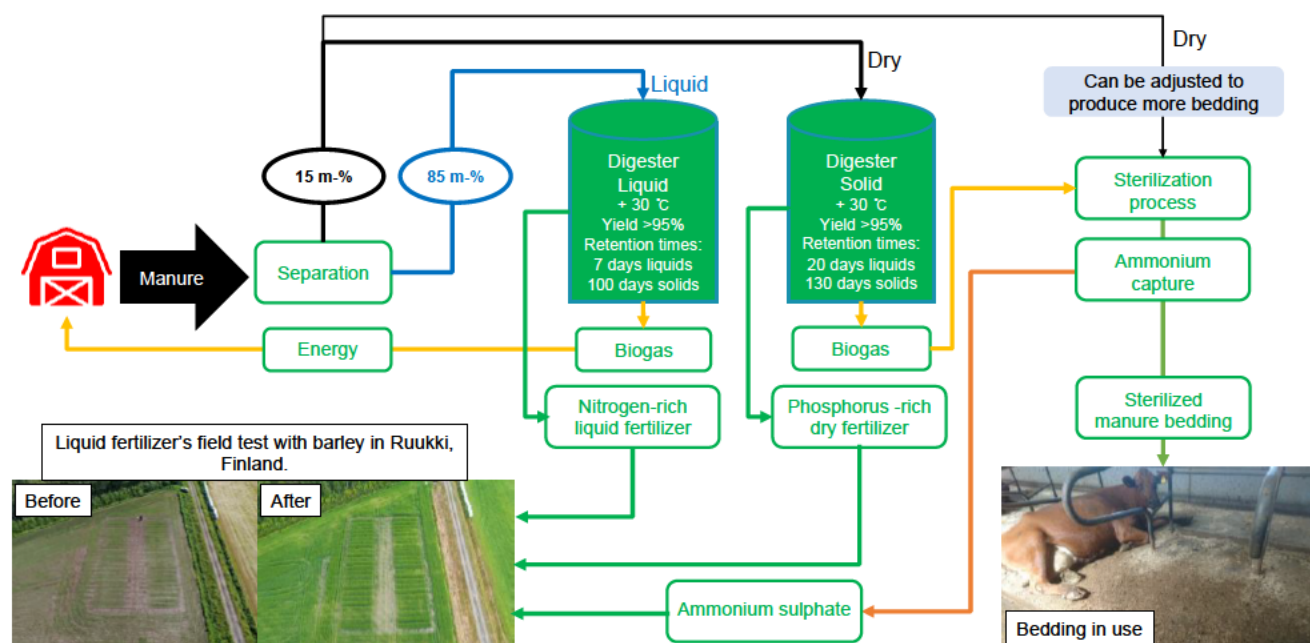


Figure 3. Bioproduct plant process. "Bedding in use" photo by Urpo Heikkinen.

Thus, the process concept speeds up digestion, maximizes biomethane yield while lowering costs, creating monetary benefits and reducing emissions. Biometa's HEGSB technology operates as follows (Figure 4):

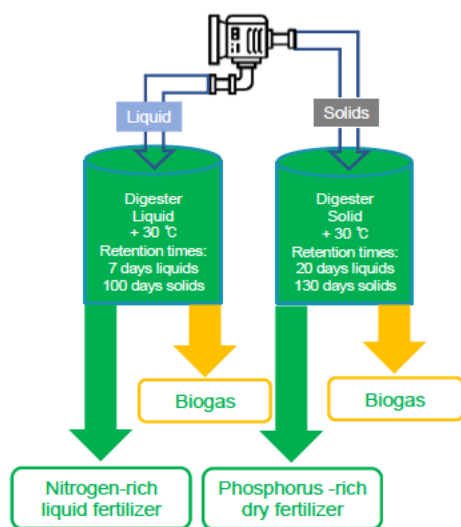


Figure 4. Biometa's HEGSB technology.

Through mechanical separation, manure is separated into liquid and solids prior to feeding into two bioreactors. Before that, a small portion of the fresh solids is redirected to a manure bedding unit. For further information, please see the earlier patent application⁷ by Biometa Finland, related to mechanical separation. For the liquid digester, the process temperature is controlled at +30 °C, promoting the methanogen populations optimally growing at this temperature level. This way, the risk of ammonia inhibition occurring is minimized, thus enabling the fast processing of liquid fraction that exhibits a higher nitrogen content.



Furthermore, the reactor's own heating requirement is reduced. The process takes place in high-rate vertical flow bioreactors, both featuring recirculation property. The liquid remains in the reactor for 7 days. Due to the reactor's hydraulic design, the up-flow velocity of the liquid inside the reactor is typically kept at 15 m/h. However, because of the solids-retaining property of this technology, the retention time of solid particles has been measured as 100 days on average. Besides methane-rich biogas, the liquid digester produces nitrogen-rich liquid fertilizer for use as an environmentally friendly fertilizer with a carbon-to-nitrogen (C:N) ratio of 9 and a chemical oxygen demand (COD) removal rate of 80%. This fertilizer product (around 85% of the total mass of manure) has been potentially authorized for use additionally on groundwater-sensitive fields at a test farm in Finland.

For the solids digester, solids are treated at a temperature of +30 °C. The operating principle is the same as in a liquid bioreactor (modified EGSB). Here, the liquid is retained for 20 days (hydraulic retention time, HRT), while solid particles are retained for 130 days on average in this reactor to ensure the highest possible fermentation efficiency. Separation is again performed on the digestate of the solids bioreactor. In this way, the digested solids fraction is a ready-made, concentrated fertilizer containing phosphorus, potassium and nitrogen. The liquid further separated from the solids digestate is utilized as liquid fertilizer, exhibiting the same properties as the digestate of the liquid reactor. The biogas generated from this bioprocess is partly used in the production of sterilized manure bedding production.

For biogas, a methane yield of 97% of the theoretical biomethane potential is achieved due to the long retention time of solid particles in both reactors. In comparison to conventional biogas plants with a typical 85% yield for manure, an increase in biomethane production capacity is expected. This technology-based improvement minimizes the residual methane from digestates in both fractions, namely the uncontrolled release of methane into the atmosphere from the digestate.

Conventional solutions traditionally use additional feeds, such as grass or maize, to boost the amount of biogas generated. Biometa's mono-manure solution uses only the farm's own manure, therefore minimizing the retention time and the reactor size to increase profitability.

The equipment in the bioproduct plant is mostly recycled and recyclable:

- New-generation high-rate liquid bioreactor
- New-generation high-rate solid bioreactor
- Sterilized bedding production unit
- Automation system of the bioproduct plant
- Ammonia capture system
- Integrated power source: solar panels.

Sub-processes

The bioproduct plant concept includes variations of processes utilized in different industries. These sub-processes include the following:

Thermal treatment for production of sterilized manure bedding

Thermal sterilization is applied for manure bedding production. Part of the mechanically separated solids is thermally sterilized with the plant's own biogas in a drying unit. This stage also controllably releases ammonia gas, which is captured in a chemical reactor in the next stage and condensed into ammonium sulphate to be used as an optimized fertilizer. Sterilized bedding is intended for use as clean and bacteria-free animal bedding. Exhaust heat from the sterilization process is fully utilized internally for heating the bioproduct plant in cold climates.

Ammonia capture

Ammonia is captured from multiple streams at the bioproduct plant by a thermo-chemical process: from the ammonia released in the bedding production sub-process, from the liquid digestate (85% from the total mass of manure) and from the air mixture above the liquid digestate in a covered storage pool. The capturing process innovatively utilizes the liquid digestate to control the process temperature of the ammonia capture and to wash the vapors. The ammonia gas is captured into ammonium sulphate solution by scrubbing in mildly acidic conditions. As a modification to this well-known and effective technology, in the Biometa concept, the liquid effluent is both the carrier and capturing agent of ammonia, removing the need for external process water completely.

IoT, sensors, data

Smart measurements are utilized to provide data across the whole process, enabling remote optimization of the bioproduct plant in a predictive way. All stages of the sub-processes are monitored by real-time measurement. In this automation concept, data is selectively sent to BioFarm's cloud server, where a digital twin is utilized to optimize and



control all the functionalities of the bioproduct plant. Data can also be collected and further analysed in the edge computing environment regarding manure composition, enabling improvements in cattle feeding to improve animal health and fertilizer quality.

This is a far more advanced operation of farm-sized processes than existing automation systems, leading to zero-hours maintenance time for plant owners. In traditional biogas plants, about 100 hours are needed to maintain and operate the process annually. Biometa's optimization strategy involves maximizing the energy efficiency of the bioproduct plant by maintaining both bioreactors accurately at low temperature levels, namely +30 °C.

Pretreatment of organic solids



The pretreatment relates to a method and equipment for hydrolysing organic matter. A pretreatment unit (Figure 5). can be integrated prior to the solids digester to hydrolyse manure and any organic residue feeds at the farm.

Figure 5. Pretreatment unit tested by Biometa. Photo by Biometa Finland.

The method developed by Biometa comprises breaking down the cellular structure of the organic matter using thermal pressure hydrolysis. This is done under high temperature and pressure. The results of the manure solids pretreatment are shown in Section 5.2.3. For further information, please see the earlier patent application⁸ related to thermal hydrolysis.

4.2. Suitability

The bioproduct plant concept is optimally suitable for dairy farms with 50–500 head of cattle. The plants are designed to be modular and therefore easily scalable with standardized parts used in construction and assembly.

The bioproduct plant is considered a mono-manure plant without processing anything other than manure. However, other feedstocks can be utilized as well, since the technical concept allows seamless integration with feed and pretreatment for solids.



The bioproduct plant is also designed to be economically and technically viable for smaller farms, as this segment currently lacks solutions for manure processing. In this way, every farm with over 50 head of cattle can be served in terms of manure processing and biogas solutions, increasing the manure handling capacity significantly and having a true impact on economic and environmental effects.

The bioproduct plant concept is also designed to be suitable for swine farms, see the review in Section 4.4.

4.3. Bioproducts

The bioproduct plant produces four types of bioproducts:

- Biogas
- Nitrogen-rich liquid fertilizer
- Phosphorus-rich dry fertilizer
- Sterilized bedding.

In this sub-section, these products are reviewed in more depth. It must be noted that the values presented in this section are based on different test sets and series at Biometa's experimental plant and that the actual values may vary slightly across different farms, depending on multiple factors, such as the quality and solids content of the manure.

4.3.1. Biogas

The bioproduct plant's biogas is completely made of dairy cow manure and there is no need to use other feedstocks. Thanks to the powerful new-generation vertical flow bioreactors, the methane content is typically between 65% and 70% during normal operation.

The average residence time in the liquid fraction bioreactor is only 7 days, giving a methane conversion of 97%. The average residence time in the dry fraction bioreactor is designed to be 20 days, resulting in a methane conversion of 97%. The temperature in both bioreactors is maintained at around +30 °C. A post-digester is not needed thanks to the maximized fermentation efficiency.



Table 1. Bioproduct technical facts: Digestation conditions and biogas.

Technical facts, dairy manure processing	Value
Hydraulic retention time (HRT), days (liquid fraction bioreactor)	7
Hydraulic retention time (HRT), days (solids bioreactor)	20
Organic Loading Rate (OLR), kg org. material / m ³ _{reactor} · d	4
Chemical Oxygen Demand (COD) reduction, %	60
Biomethane content, %	65–70

4.3.2. Liquid Fertilizer

The bioproduct plant's liquid effluent is a fertilizer product that can be used in agriculture as it has great fertilizing properties. The liquid fertilizer is high in nitrogen and low in phosphorus. Because the product has low levels of phosphorus, it can be applied more to soils that are rich in phosphorus compared to untreated manure slurry.

The nutrients in the liquid fertilizer are in liquid form, so they are easily available for plants to use. The amount of soluble nitrogen is especially high, which means that plants can use the nitrogen well. The C:N ratio of the liquid fertilizer is 9, which means that this fertilizer is optimal for areas that have a short growing season and where plants need a quick nitrogen uptake. For ideal nutrient utilization, it is recommended to inject the liquid fertilizer into the ground. This way the ammonia emissions can be further minimized.

Table 2. Bioproduct technical facts: Liquid fertilizer.

Properties of liquid fertilizer	Value
Soluble nitrogen, kg/t	2.9
Total nitrogen, kg/t	4
Phosphorus, kg/t	0.6
Potassium, kg/t	3.2
C:N ratio (carbon-to-nitrogen ratio)	9
Chemical Oxygen Demand (COD), reduction %	80
Volatile solids, % of dry matter	66.8
Total solids, %	3



Crop yield tests

Prolific testing (Figures 6 and 7) on liquid fertilizer digestate was done in the summer of 2019. The tests were performed at Luke's (Natural Resources Institute of Finland) experimental field in Ruukki. Altogether 2000 litres of three different digestates were delivered to the test field from the pilot plant. The expertise of the local farmer, Proagria and Luke was utilized in the test planning.



Figures 6 and 7. Tests on liquid fertilizer in Luke's experimental field in Ruukki in the summer of 2019. Photos by Biometa Finland.

Field tests were conducted to measure the nutrients and crop yield. Three sections were tested: untreated (no manure or fertilizer); separated manure; and liquid fertilizer from the pilot plant. After 105 days, the key outcome was a +13% increase in the yield of barley, namely 575 kg/ha more compared to the use of untreated manure.

Because the summer of 2019 was low in rainfall, it stopped weeds from growing and therefore they were not visible in the test plots, so observations of lessening the use of pesticides when using liquid fertilizer remained unproven.

4.3.3. Dry Fertilizer

The bioproduct plant's dry fertilizer is completely made of dairy cow manure. It is high in phosphorus and low in nitrogen. It has a lot of organic matter, so it is ideal for boosting the ground's microbial activity. The nutrients are in the organic matter, and because the dry fertilizer is high in organic matter, it is a long-term nutrient supply for plants. Organic



matter also plays a big role in ground water management. Land that has lots of organic matter keeps the soil moist longer, which helps plants to obtain a stable water uptake.

The dry fertilizer can be used in soils that need organic matter and are low in phosphorus. A nitrogen fertilizer is recommended to be used with it for optimal plant growth. A dry fertilizer can be applied with dry manure spreading equipment. The best fertilization result can be obtained by injecting the dry fertilization into the ground with special equipment or by broadcasting by the incorporation method when the soil is tilled.

Table 3. Bioproduct technical specifications: Dry fertilizer.

Nutrient content of dry fertilizer	Value
Soluble nitrogen, kg / tonne	2.1
Total nitrogen, kg / tonne	4
Phosphorus, kg / tonne	2.1
Potassium, kg / tonne	0.8
Organic matter, % of dry matter	89.1
Dry matter content, %	24

4.3.4. Sterilized Bedding



The bioproduct plant's bedding is intended for animals and made completely from dairy cow manure. The dry matter in the process is sterilized and ammonia is extracted from the manure. It can be used on-farm as animal bedding or further processed into a substrate for use in farming. It is suitable for example for dairy and livestock farms, poultry farms, swine production and stables. The sterilization process destroys harmful bacteria. The product is light in weight, homogenous, it has good water absorption capacity and does not dust. All-in-all, it is safe, easy to use and store.

Sterilized bedding is a sustainable, excellent and natural, fully bio-recycled product with optimal characteristics. Producing the bedding eliminates the need for the farmer to buy bedding from outside the farm. The bedding's packaging and transportation methods are customizable, so farmers can also sell the bedding material to other farms if they have an official seller's permit.



Table 4. Bioproduct technical specifications: Sterilized bedding.

Technical Facts	Value
Raw material	Solid fraction of manure
Dry matter content, %	60
Moisture, %	40
Density, kg/m ³	200
Storage	Indoors
Packaging	Customizable

According to the Finnish Food Authority's accredited laboratories, the process destroys the harmful bacteria examined or their concentration was under the limits that were set (Table 5). A seller's permit is a guarantee that the process produces homogenous manure bedding that is safe for livestock. Table 5 shows one bedding sample analysis where the bacteria population was examined before (input) and after (final product/output) the bedding manufacturing process. The samples were examined for heat-resistant bacterium coli, *E. coli*, salmonella, enterobacteria and clostridium perfringens bacteria.

Table 5. Bacterial analysis of sterilized bedding. The input is untreated matter that enters the process. Final product means the treated matter that is suitable for bedding material. The marking "<10" means that the value is below the measurable resolution.

Analysis	Method	Unit	Measurement uncertainty	Input	Input	Final product	Final product
Heat-resistant bacterium coli	NMKL 125:2005	pmy/g		9 000		<10	
<i>E.coli</i> *	NMKL 125:2005	pmy/g				<10	
<i>E.coli</i> , confirmed *	NMKL 125:2005	pmy/g		9 000			
Enterobacteriaceae 37C 24h * 1)	NMKL 144:2005	pmy/g			54 000		<10
Clostridium perfringens 37 °C 24h * 1)	NMKL 95:2009	pmy/g			40		<10
Salmonella *	ISO 6579-1:2017	/25g		Not found		Not found	
Moisture content * 1)	NMKL 14:2012 mod.	g/100g	4%		76		16.9
Dry matter * 1	NMKL 14:2012 mod.	g/100g	4%		24		83.2
*= accredited method. 1)= analysis contracted out to SeiLab, FINAS T106 (EN ISO/IEC 17025)							



The mechanical qualities of the sterilized bedding were examined by visual inspection, and by measuring it experimentally. Based on the observations, bedding that has about 60% of dry matter does not dust, retains its volume compared to the baseline and does not stick to the hooves of animals when stamped on. The process generates a great deal of bedding material and based on analysis and calculations, the farmer can eliminate the need for bought-in bedding completely.

4.4. Solution for Swine Farms

The bioproduct plant concept has been developed for swine farms as well. Technically, the same concept is applicable for swine farms and they present a significant additional market segment for the solution. However, there are some differences in the process as, for example, sterilized bedding production is excluded.

The process is highly scalable for swine farms, estimated to be able to handle 190 000 metric tons of swine manure per year. Figure 8 shows a process chart for the swine farm solution.

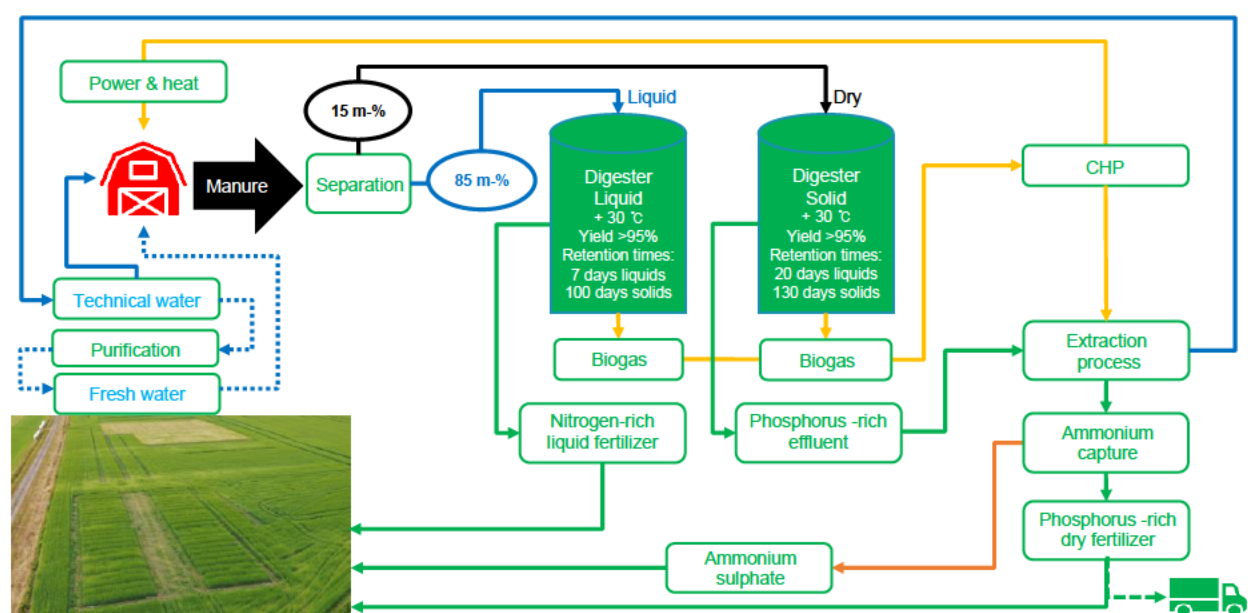


Figure 8. Bioproduct plant concept for swine manure processing.



As seen in the process figure, some adaptations have been made to the process in the swine farm version. Some features of the solution for swine farms are listed below:

- Reactor technology is the same as for dairy farms
- Robust phosphorus removal process is featured in the main process, unlike dairy farm solution
- Ammonia capture process included
- Reactor size is scaled to suit the manure amount of the farm. Three bioproduct plants, total maximum capacity 190 000 t_{manure}/a (Figure 9)
- Integrated, efficient processes
- Removes the need for post-digester
- Prevents harmful emissions.

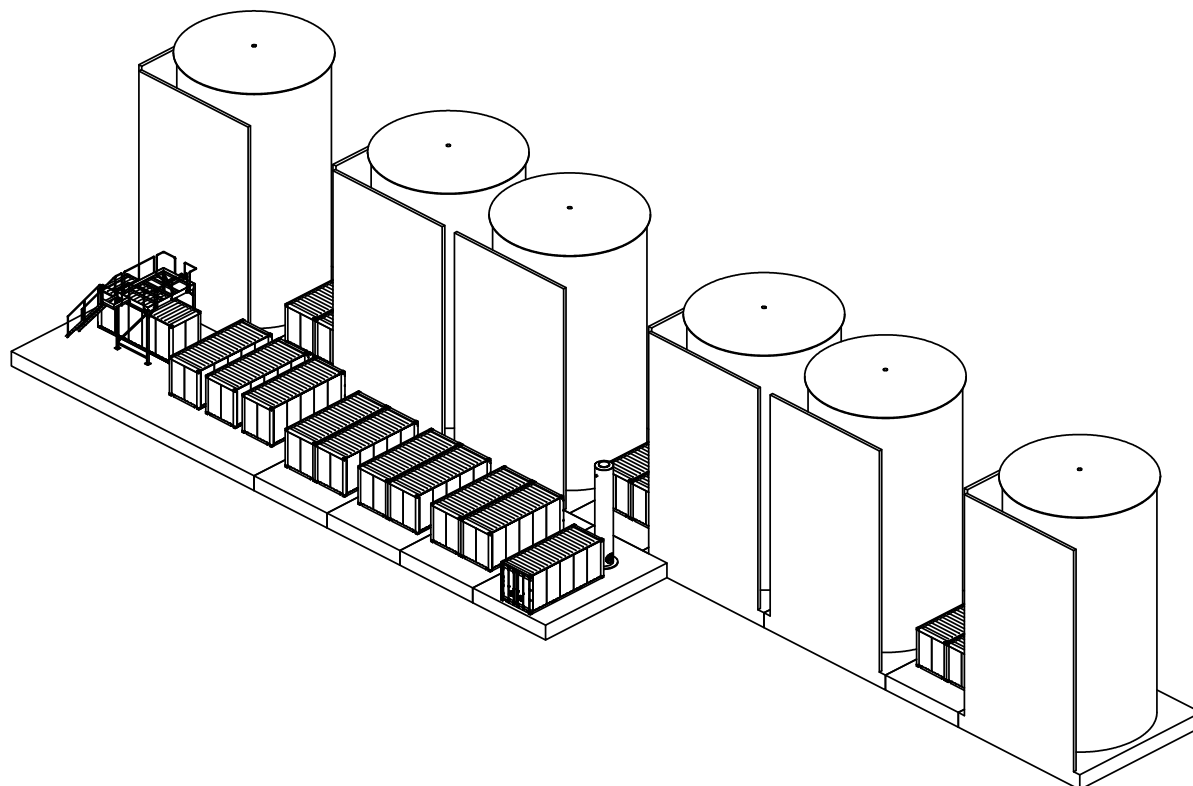
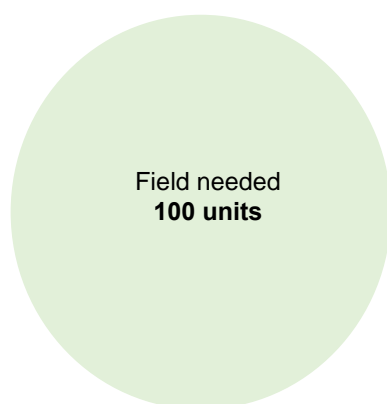


Figure 9. Schematic of bioproduct plant for swine manure processing with a nominal capacity of 190 000 t/a.



In several areas worldwide, phosphorus levels in fields are high, as too much untreated manure is applied. This can lead to harmful eutrophication and leakage into the soil and nearby waterbodies. The bioproduct plant can minimize the amount of fertilizer applied to a field by handling the farm's manure and transforming it into optimized fertilizers. The bioproduct plant can therefore improve the condition of soils and nearby waterbodies by reducing eutrophication and leakage (Figure 10).

Before bioproduct plant



Untreated manure:
• 5 000 t



Manure	5 000	tonnes
Limitations in this simulation:		
Max amount of nitrogen	170	kg/ha
Max amount of phosphorous	17	kg/ha

After bioproduct plant



Liquid fertilizer:

- 3 800 tonnes



Solid fertilizer:

- 650 tonnes
- Phosphorous-rich fertilizer
- Good for grass
- Can transported from the farm



Figure 10. Scenario of reducing spreading area of 5 000 t/a manure by processing it in the bioproduct plant.

On a swine farm, the bioproduct plant can handle the farm's manure, reducing the area needed for manure spread, cutting harmful environmental emissions and bringing significant economic benefits for the farmer.



5. Background and R&D

Biometa Finland Ltd was set up by technical experts and private investors who understood the potential of the bio-circular economy and both of its sides: business and environment. The drive to develop a solution to untap this potential was spun off into a company, Biometa Finland Ltd, in 2008.

Over the years, Biometa Finland has followed a product development path, achieving multiple concrete, measurable goals. Several pilots have been made during the development stages and the final full-scale demonstration project gained the Seal of Excellence quality label from Horizon Europe's EU EIC Accelerator programme.

During the development stages, understanding of the economic and environmental challenges became clear. This solution is designed to address the common global challenges faced by the agricultural sector, specifically for the small and medium-sized farm segments:

- economic
- environmental
- technical challenges.

The idea is to maximize bioproduct production using all available methods since there exists an environmental risk of emissions from undigested biomass. Besides, using additional feeds enlarges the reactor size making the innovation too costly for smaller farms.

The aim is to utilize and transform farm manure into valuable bioproducts, maximize biogas yield and reduce manure-based emissions. This ensures that smaller farms also have access to this solution, which is crucial in solving agriculture's core challenges on a wider scale.



5.1. Development Stages

Since the company was founded, several prototypes have been built and deployed in the field, undergoing numerous tests and experiments that have proven the technology and its benefits (Figure 11). All the tests have been made utilizing dairy farm manure. The solution has now reached technical readiness level⁹ TRL 6, after being validated in field tests on a working farm.

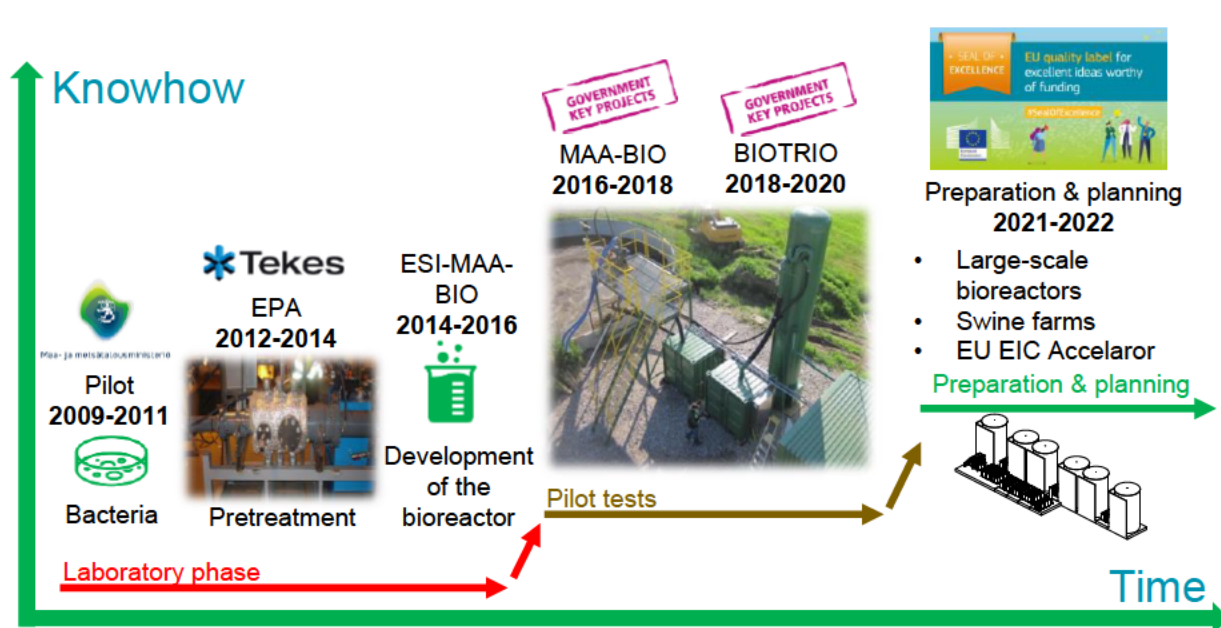


Figure 11. Biometa's research and development path.

Different projects and their results as well as the time evolution of the research and development phases are described in Tables 6 and 7 below. Each table lists a description of each project conducted and a summary of the results.



Table 6. Research and development history of Biometa Finland Ltd.

Laboratory and pilot phases	Project outcomes
Pilot project (2009 – 2011)	<ul style="list-style-type: none"> • Planning and start-up of pilot plant • Utilizing anaerobic digestion with liquid and dry fractions • Financed by Biometa's owners and The Finnish Ministry of Agriculture and Forestry • As a result, basis was made for R&D framework and expertise in utilizing anaerobic digestion with dairy manure
EPA project (2012 – 2014)	<ul style="list-style-type: none"> • Developed and piloted farm-scale pretreatment process • Financed by Biometa's owners and TEKES (Business Finland) • As a result, a working prototype of the pretreatment process was built
ESI-MAA-BIO project (2014 – 2016)	<ul style="list-style-type: none"> • Preparations of MAA-BIO project & partnership network • Laboratory-scale test for bioreactor • Utilization of principles from UASB reactor technology • Concept planning for bioproduct plant • Utilization of results from previous projects • Financed by Biometa's owners • As a result, parameters were made ready for deploying 1st generation bioproduct plant concept and: <ul style="list-style-type: none"> ◦ Commencing pilot-scale bioreactor technology using liquid fraction ◦ Piloting dry fraction processing units
MAA-BIO project (2016-2018)	<ul style="list-style-type: none"> • Planned and start-up of energy- and cost-efficient technology: <ul style="list-style-type: none"> ◦ Bioreactor scaled up x200 from laboratory size and piloted in a working farm using liquid fraction ◦ Commenced first pilots of a sterilized bedding production unit ◦ Commenced first pilots of producing inorganic matter from manure ◦ Built and deployed automation system of the pilot plant • Financed by Biometa's owners and key Finnish government projects (ELY) • As a result: <ul style="list-style-type: none"> ◦ 1st generation bioproduct plant concept implemented ◦ Digester liquid fraction ready for field tests ◦ Parameters ready for piloting 2nd generation sterilized bedding production unit
BIOTRIO project (2018-2020)	<ul style="list-style-type: none"> • Three farms were involved in this project: <ul style="list-style-type: none"> ◦ Simulated farm nutrient circulation with actual data ◦ Simulated benefits when utilizing plant's liquid and dry fraction as fertilizer with actual data • Continued pilot-size bioreactor test in a working farm using liquid fraction: <ul style="list-style-type: none"> ◦ Developed predictive modelling tools ◦ Planned and implemented field test for liquid fraction • Piloted second-generation sterilized bedding production unit • Bioproduct plant concept gained: <ul style="list-style-type: none"> ◦ Environment permit ◦ Construction permit ◦ Investment aid (for customer) • Financed by Biometa's owners and key Finnish government projects (ELY) • As a result, 2nd generation bioproduct plant concept ready for full-scale demonstration: <ul style="list-style-type: none"> ◦ New-generation high-rate liquid bioreactor ◦ New-generation high-rate solids bioreactor ◦ Sterilized bedding production unit ◦ Automation system of the bioproduct plant ◦ Ammonia capture, system-level integration



Table 7. Research and development history of Biometa Finland Ltd.

Preparation & planning	Project outcomes
EU EIC Accelerator (2021-2022)	<ul style="list-style-type: none"> Applied to EU EIC Accelerator to develop a new and advanced full-scale bioproduct plant to prepare for and demonstrate its readiness for commercialization: <ul style="list-style-type: none"> Technical development: prototype planning, procurement, installation, and operation Verification and scale-up: plant operational and output testing, product testing, IoT enhancement, product quality control and manufacturing scale-up Commercial development: market and customer research, sales model development, IPR, communications and further funding As a result, Seal of Excellence quality label
Large-scale bioreactors (2021-2022)	<ul style="list-style-type: none"> Concept planning: <ul style="list-style-type: none"> Process 20 000 - 60 000 tonnes of manure yearly Dairy and swine farms Requested by a potential customer Utilization of company's technology: <ul style="list-style-type: none"> New-generation high-rate liquid bioreactor New-generation high-rate solid bioreactor Simulations included: <ul style="list-style-type: none"> Process parameters Monetary benefits Environmental benefits As a result, concept ready for full-scale demonstration
Swine farms (2021-2022)	<ul style="list-style-type: none"> Concept planning: <ul style="list-style-type: none"> Process up to 190 000 metric tons of manure yearly Targeted for swine farms Option for phosphorous extraction process Requested by a potential customer Utilization of company's technology: <ul style="list-style-type: none"> New-generation high-rate liquid bioreactor New-generation high-rate solid bioreactor Sterilized bedding production unit Ammonia capturing system Simulations included: <ul style="list-style-type: none"> Process parameters Monetary benefits Environmental benefits As a result, concept ready for full-scale demonstration



5.2. Experiments

In this section, a deeper review of the projects including the pilot plant is conducted. The test series in the pilot phase were conducted on:

- a working dairy farm in Kempele, Finland, where the test series began in 2016
- Luke's (Natural Resources Institute of Finland) experimental field in Ruukki in 2019
- Biometa's premises.

The test series and experiments were carried out in two different government key projects: the MAA-BIO project, and the BIOTRIO project.

Test series and experiments were carried out firstly to develop, build and scale up the pilot plant and, secondly, to ensure the complete functionality of the bioproduct plant's core and sub-processes. The test series were finished by the end of 2022 with multiple positive, measurable results.

5.2.1. MAA-BIO project (2016-2018)



The MAA-BIO project continued the projects that started with experimental research leading to the productization (pilot project and EPA project).

During the MAA-BIO project, a pilot plant (Figure 12) was built and integrated on a working dairy farm in Kempele, Finland. During the project, the process was run and the parameters started to take shape. Information about the project's key facts is given below.

Figure 12. Pilot plant in operation at a dairy farm during the MAA-BIO project. Photo by Biometa Finland.



During the testing period (2016-2018) the following outcomes were recorded:

- Pumped 186 000 litres of liquid fraction
- Separated 219 000 litres of manure
- Separated 33 000 kilogrammes of solids
- Residence time inside reactor: 10 days
- 100+ manure analyses
- 200+ measuring gas components
- Methane recovery: 6.5 CH₄ m³/t fed liquid fraction
- Methane content: 65–70%
- Outdoor temperatures: minimum -35 °C and maximum +33 °C
- Average temperature inside the reactor: +31 °C.

The MAA-BIO project's core results were as follows:

- According to the analysis results, efficient management of the liquid fraction of manure leads to an approximately 75% decrease of organic matter in field application compared to the starting point (application of manure without processing)
- According to the analyses made, the environmental burden of manure is decreased by 60% measured in terms of chemical oxygen demand (COD-Cr)
- Simultaneously, the fertilizer properties of the applied end product – the liquid fraction of processed manure – are improved by approximately 40% regarding soluble nitrogen, and the annual amount of phosphorous in the liquid is decreased by 30%
- Processing reduces transportation and application costs: according to the analyses, the mass of material applied to fields decreases by approximately 2% a year.

5.2.2. BIOTRIO project (2018-2020)



In 2018, the BIOTRIO project began, which was a continuation of the previous MAA-BIO project and the development of an industrial-scale bioproduct plant. The BIOTRIO project focused more closely on the activities of a decentralized bioproduct plant and on the specific characteristics of bioproducts.

Key facts of the project:

- In this project, three different farmers were included, and various simulations were performed with their actual data to monitor the benefits of the optimized fertilizers



- During the project, numerous tests on the liquid fertilizer digestate were done at Luke's experimental field in Ruukki, Finland. Altogether 2000 litres of three different digestates were delivered to the test field from Kempele's pilot plant (Figure 13). The expertise of the farmer, Proagria and Luke was utilized in the planning and execution of the tests
- An enhanced prototype of sterilized bedding production was piloted, and various tests were made during the project. This was to ensure the homogeneity of the bioproduct and the wellbeing and health of the livestock
- Pilot-size bioreactor tests continued at a working farm using the liquid fraction.



Figure 13. Pilot plant in Kempele in operation during wintertime. Photo by Biometa Finland.

5.2.3. Results of the projects

During these projects, many positive, measurable goals were achieved. The test results from pilot phases were collected and analysed from:

- Pilot plant located at a working dairy farm in Kempele
- Luke's (Natural Resources Institute of Finland) report
- Tests and experiments done on Biometa's premises
- Simulations using real data from farmers.



Sterilized manure bedding



For the sterilized manure bedding (Figure 14), various tests were made from different projects and experiments to ensure the product's homogeneity and the wellbeing and health of the livestock.

Regarding sterilized bedding production, in different tests and projects, it was found that the process can be adjusted to produce more bedding if needed, for example during summertime when energy usage for heating is lower.

Figure 14. Sterilized manure bedding produced at the pilot plant. Photo by Biometa Finland.

In the projects, the company further explored the possibility of sterilized bedding sales. Based on discussions with the Finnish Food Authority, a cascade-evaluation procedure for sterilized manure bedding would be needed if the bedding is sold outside the farm.

The bioproduct plant's process produces lots of bedding and based on analyses and calculations, the farmer can eliminate the need for purchased bedding completely.

Sterilized bedding as a substrate

During the projects, the usage of sterilized bedding as a substrate was explored. The parameters of the sterilized bedding production unit were modified to find the optimal processing conditions and the potential of manure-based sterilized substrate. The sterilization process destroys harmful bacteria, so the final product is safe to use.

The tests and experiments found that the substrate was high in nutrients and contained plenty of organic matter. The results further showed that the substrate could be mixed with acid and low-in-nutrient substrates to maximize the optimal growth of plants. It could also be used in professional cultivation.

All-in-all, based on the tests, the sterilized bedding has the potential to be used as a substrate and is ready for the next phase of testing. For the substrate, farmers can use it themselves and/or sell the excess if they have an official seller's permit.



Increased crop yield from using the plant's liquid fertilizer

During the projects many different crop yield experiments were carried out to test the effect of the liquid fertilizer from the bioproduct plant on crop yield.

The results showed that the bioproduct plant's liquid fertilizer is a mass product since 85% of the manure's mass is processed further into liquid fertilizer. The liquid fertilizer was found to be high in nitrogen and low in phosphorus and its nutrients to be in liquid form. The results further revealed that more liquid fertilizer could be applied to soils that are rich in phosphorus compared to untreated manure slurry.

Based on the prolific testing done on the liquid fertilizer, there was a +13% increase in crop yield compared to untreated manure.

Optimizing field fertilization

In the BIOTRIO project the optimization of aerial field fertilization was also examined. The tests were carried out based on a comparison between untreated slurry and liquid and solid fertilizer from the pilot plant.

Based on the analysis, the solid fertilizer exhibits higher phosphorus levels than liquid fertilizer and therefore suits grass fields better. The liquid fertilizer, in turn, is more suitable for grain, because its nutrient balance is optimal for the nutrient needs of grain. Overall the liquid fertilizer has more nitrogen and less phosphorus.

After several simulations the conclusion was that farmers can save up to 6% on fertilizer costs by using liquid and solid fertilizers from the bioproduct plant compared to using untreated manure slurry.

Optimizing transportation

At the same time as optimizing field fertilization, the decrease in transportation costs of the fertilizing process was also investigated.

A simulation was made for one farm. The costs of transporting and applying slurry (liquid and solid digestate) were taken from public sources. For liquid fertilizer, the costs of transporting and applying manure slurry were used.

The simulation was carried out using an MS Excel based calculator, in which the conclusions from the liquid fertilizer optimization were used. Along with location information, the calculation also considered the block-specific application quantities of organic fertilizers and the costs of applying fertilizers. Fertilizing of field blocks can be



executed in an effective way with different variations, so a few simulations were made to account for the variations in transportation costs.

Based on conservatively estimated results, by optimizing fertilizing and transportation, farms can save about 10% on annual costs of applying fertilizers.

Efficiency of digestion

The production of biogas was closely monitored throughout the projects, including the pilot plant. The results of biogas production were promising, with the average retention time in the liquid fraction bioreactor being only 7 days with a methane conversion of 97%. For the dry fraction bioreactor, the retention time was 20 days, with an identical 97% methane conversion. The powerful, new-generation vertical flow bioreactors were operated further and tested in the projects, with a typical methane content of between 65% and 70% at nominal capacity.

Based on these results, the temperature in both bioreactors should be maintained at around +30 °C. The need for a post-digester is eliminated due to maximized fermentation efficiency.

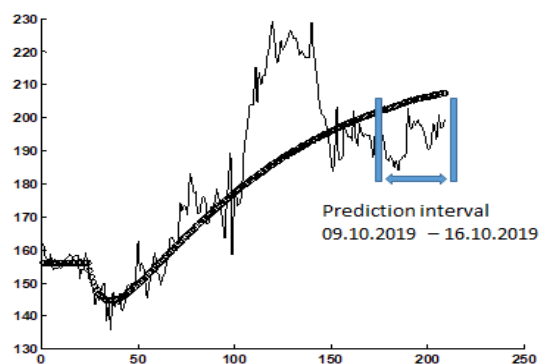
The bioproduct plant's biogas production was found to be more efficient than with the current state-of-the-art technologies. The throughput of the bioprocess is 3–5 times faster, the methane yield 10–15 percentage points higher and the energy consumption due to the lower processing temperature 30–35% lower than in typical current biogas plants that process dairy manure.

Predictive modelling

Predictive modelling was applied to provide forecasts on biogas production in the case of changes in organic loading rates. The developed models could provide a maximum forecast horizon of three weeks for predicting biogas production.

In the BIOTRIO project, predictive modelling (Figure 15) was utilized to forecast the biogas production of the pilot plant. The algorithm (black line) was able to forecast real biogas production even when one biogas flowmeter showed faulty values.

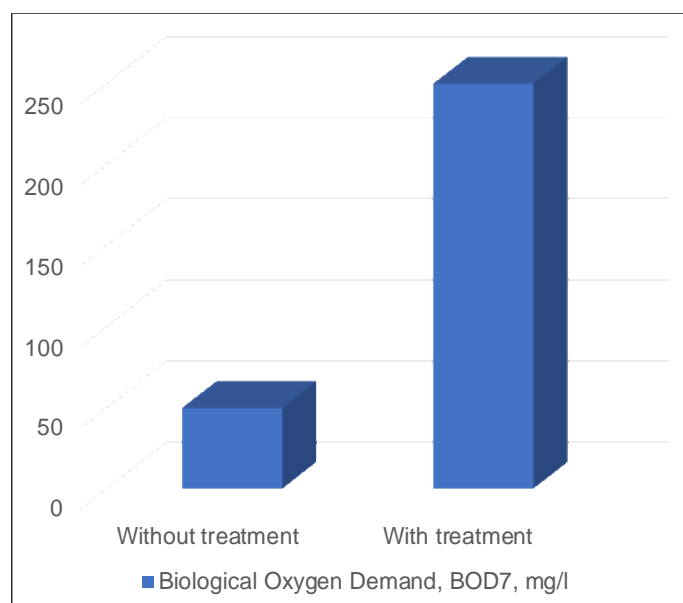




Predictive modelling together with a digital twin improves the commercial readiness of the bioproduct plant concept, and is the basis of remote-controlled, decentralized plants.

Figure 15. Predictive modelling of pilot plant biogas production.

Pretreatment of dairy manure



During the projects, the biodegradability of the manure's organic solids was explored (Figure 16). In order to speed up the digestion process, pretreatment can be an effective method to increase the availability of organic matter to methanogens. In this aspect, the more biodegradable organic material that is available, the more biogas can be expected to be produced. A typical measurement of biodegradability is the biological oxygen demand (BOD).

Figure 16. Biodegradability of manure's solid fraction without and with pressurized thermal hydrolysis during test campaigns, measured as biological oxygen demand (BOD7, mg/l).



6. Bioproduct Plant and the Environment

The bioproduct plant has several positive environmental effects on the farm. It can reduce the greenhouse gas emissions in manure handling, livestock feed production, electricity, fuel and heating. It can reduce eutrophication of the soil and leakage into nearby waterbodies. It can also reduce the ammonia emissions on the farm as well as the chemical oxygen demand (COD).

Biometra has carried out carbon footprint calculations and simulations regarding the bioproduct plant. The simulation and calculations were executed by a widely known, independent third party called Envitecpolis Ltd. In the simulation, the carbon footprint of a simulated farm was calculated with and without a bioproduct plant in operation on the farm. The calculations were done by the extensively used Cool Farm calculation tool and were based on IPCC calculation methodology.

The assumptions for the calculation were as follows:

- Calculate carbon dioxide, nitrous oxide and methane emissions which can be converted into carbon dioxide equivalents (CO₂e)
- Take into account emissions from fertilizers, pesticides and feeds.

Basic information on the simulated farm:

Energy and Fuels	Value
Electricity consumption	180 000 kWh/a
Electricity source(s)	Normal mains electricity
Heating fuel(s)	Wood chips, no effect on calculations
Fuel consumption	Fuel oil 18 000 l/a Diesel 1000 l/a
Production	
Milk	1 200 000 l/a
Fat	4.3%
Protein	3.5%
Animal Information	
Dairy cows	120 head
Main breed	Holstein
Manure storage	Slurry
Bedding	Straw
Feed	Robot feed Silage 74.3%, barley 15.2%, other 10.5%



Cultivation	Silage	Barley	Oat
% of area	58.1	35.5	6.4
Slurry, cow, m3/a	1500	600	100
Application method	Injection	Injection	Injection
Dry manure, cow, m3/a		100	
Application method		Injection	
Extra information	No liming No changes in land use Soil coarse: fine sand High mulch levels pH 5.5 – 7.3		

The division of carbon emissions on the simulated farm is presented in Figure 17. These emissions show the situation before the installation of the bioproduct plant.

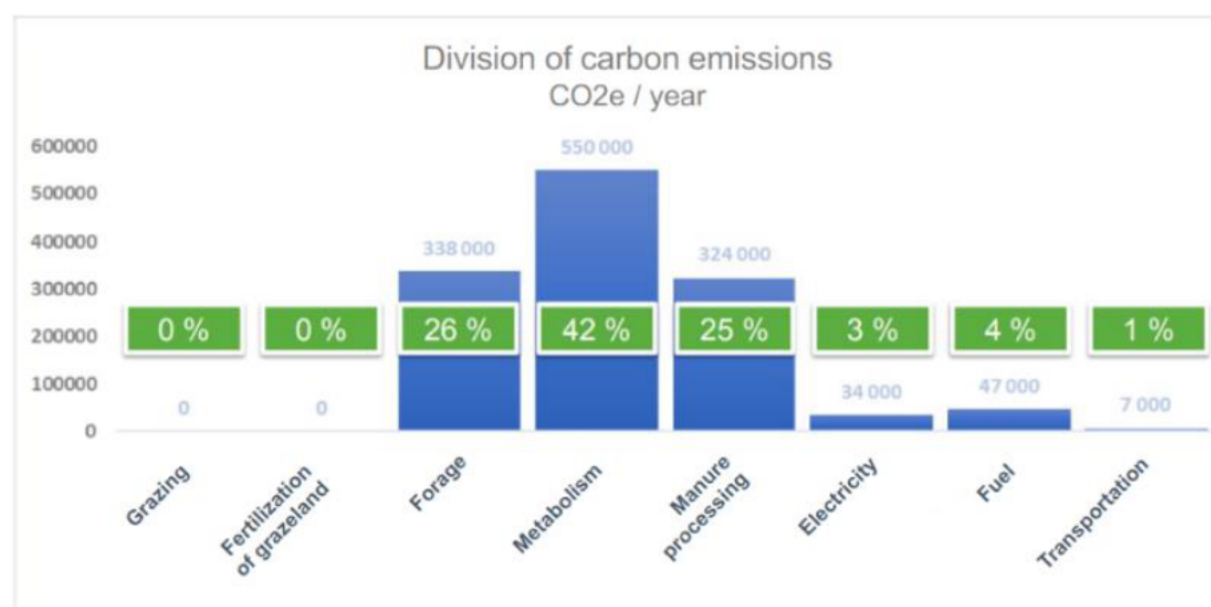


Figure 17. Division of carbon emissions on the example farm before bioproduct plant.

Over 50% of the manure-induced emissions were caused by forage, namely livestock feed and manure processing. Other emission sources, such as electricity, fuel and transportation, contributed to the overall emissions but were not as crucial on this example farm, accounting for 3%, 4% and 1% of the emissions, respectively.

Figure 18 illustrates the division of carbon emissions on the example farm after the bioproduct plant was in operation. As can be seen from the graph, the bioproduct plant had a significant lowering effect on the emissions arising from forage/feed, electricity, fuel, transportation and mainly the emissions from manure processing.



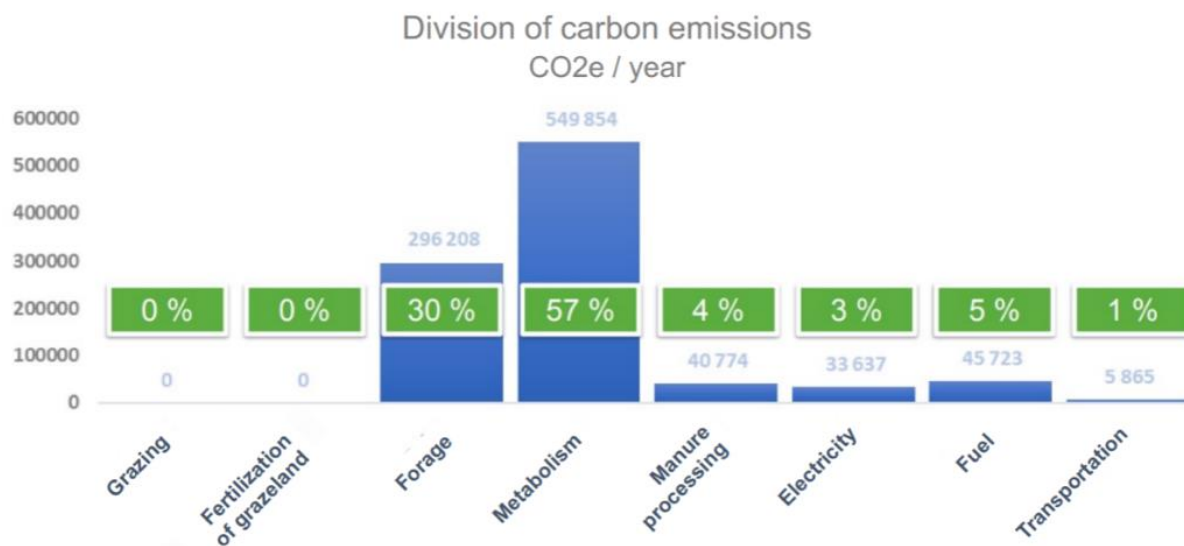


Figure 18. Bioproduct plant's effect on farm's annual carbon emissions.

In Figure 19, the results of the bioproduct plant operating on the farm can be seen. Overall, the simulation results showed that the manure handling GHGs decreased by 87% when a bioproduct plant was in operation. The GHGs that arose from feed production decreased by 12%. The bioproduct plant also had a lowering effect on electricity, fuel and transportation emissions.

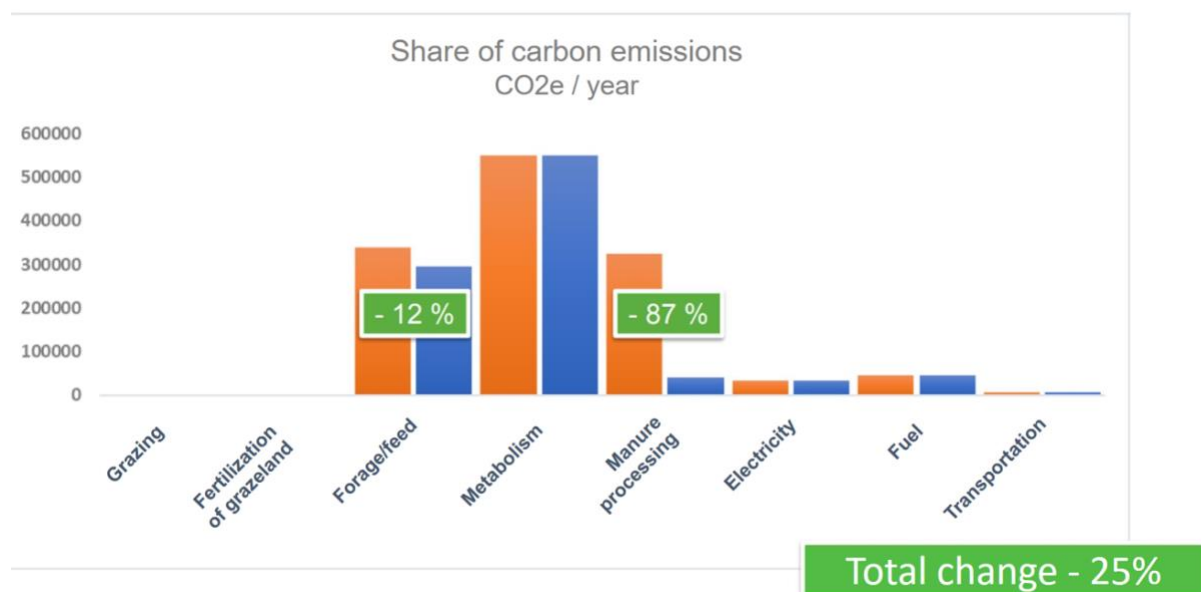


Figure 19. Reduction percentage of total emissions due to bioproduct plant operation on the farm.



Based on the simulation and the calculations, the bioproduct plant's overall reduction effect on the farm's GHGs is estimated to be –25% per kilo of milk produced.

For example, converted into car kilometres, the reduction in carbon emissions is about 2.5 million kilometres per year. Alternatively, when converted to forest carbon, the plant corresponds to an average forest growth of about 80 hectares.

6.1. Greenhouse Gases

As indicated in the above section, the carbon calculation carried out by an independent, third-party research organization showed the bioproduct plant could decrease manure processing GHG emissions by 87%. The bioproduct plant can also decrease emissions arising from livestock feed, electricity, fuel, and transportation.

Other GHG emission reductions include for example a decrease in the transportation of manure. The bioproduct plant can decrease the amount of manure spread on fields, which can reduce the carbon emissions related to manure transportation.

Through the production of farm-specific sterilized bedding, wood- or peat-based purchase beddings can be eliminated and thus the carbon emissions arising from the transportation can be decreased.

6.2. Ammonia

Based on the estimations, the bioproduct plant concept can reduce approximately 50% of the total manure-induced ammonia emissions by utilizing the bioproduct plant's multiple-step handling of nutrients and the integrated ammonia capturing sub-process.

In the farm-scale process, the ammonia from the manure is captured and transformed into ammonium sulphate. The process utilizes solely the bioproduct plant's own internal material flows and the excess heat is used as the plant's own energy source.

Easily evaporating ammonia is mainly present in the liquid fraction that is temporarily stored within compact manure coverage and later injected into the field below the surface. This prevents the ammonia emissions from being emitted from manure storage and spreading. The process essentially transforms harmful environmental effects into plant fertilizer. The ammonia emission reduction process is as follows (Figure 20).



% = % of ammonia emissions

Before



After

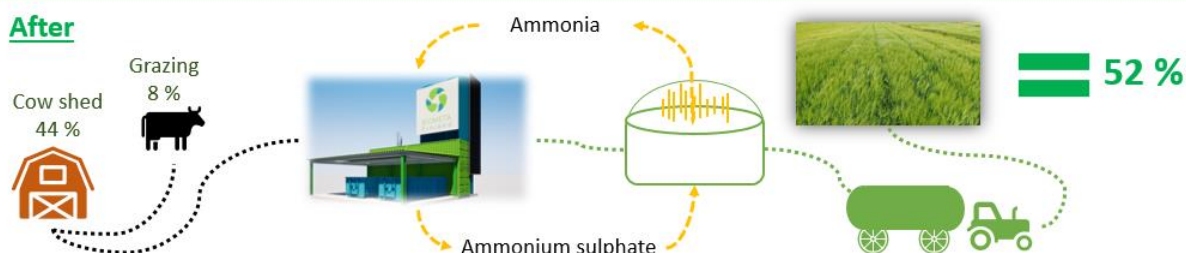


Figure 20. Ammonia emission reduction by a bioproduct plant on the farm.

6.3. Chemical Oxygen Demand

The bioproduct plant also has a major effect in reducing the chemical oxygen demand (COD) in the process.

Chemical Oxygen Demand is a metric for the concentration of potentially harmful organic residues in liquid. It is typically used to determine the cleanness of water after wastewater treatment. The higher the level of COD, the more likely the liquid contributes to the increase of the eutrophication effect when spread on the soil.

Manure processing in the bioproduct plant reduces the measured COD of the liquid effluent in field application by 60% compared to raw sludge (measured average reduction during the two-year test period).

6.4. Other Environmental Benefits

In addition to reducing emissions on the farm, the bioproduct plant has many other environmental benefits. These include the following:

- Nutrients in the liquid fraction of the bioproduct plant are transformed into a more soluble form for plants, which decreases water leaching as plants use nutrients more efficiently and reduces the need to purchase energy-intensive fertilizers



- A 40% decrease in manure organic matter as a result of the treatment process compared to the application of untreated manure, which has a significant impact on the reduction of environmental load in the field and nature (percentage reduction of organic matter studied and measured)
- Transfer of 35% of the phosphorus in the liquid fraction to the solid fraction by separation, allowing the precise optimization of the nutrients with two different types of fertilizer. This can improve the soil's overall well-being and condition
- A 30% reduction in total nitrogen in field application compared to untreated sludge application (measured)
- Significant reduction in manure odour
- Reduced circulation of weed seeds from manure to field.



7. Business Aspects

In this section the economic dimension of the bioproduct plant concept will be presented and reviewed. The bioproduct plant has always been developed with the increase of small to medium-sized dairy farms' profitability and self-sufficiency at the core. By producing valuable bioproducts, the bioproduct plant concept can provide significant monetary benefits for the farmer. For the company, there exists a huge, untapped global market for the bioproduct plant concept.

7.1. From the company's point of view

Biometa's customers are dairy farms with 50–500 head of cattle. The initial target segment, which does not currently have a fully suitable solution, are dairy farms with 50–200 head of cattle. There are approximately 90 000 such farms in Europe. At a later stage, farms with up to 500 cattle will also be targeted, expanding the potential customer base to approximately 125 000 farms. Swine and poultry farms can also be targeted in the future.

The bioproduct plant is a highly scalable innovation (Figure 21) due to its modularity. The plant is constructed and assembled using standardized parts which makes plant production smooth and easy. Scaling up for bigger farms is designed to be straightforward; it includes adding more reactors to increase the manure handling capacity of the plant.

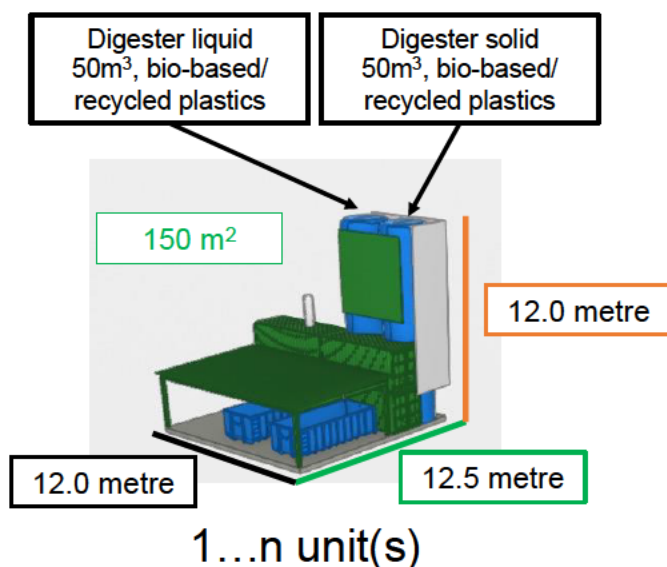


Figure 21. Bioproduct plant's scalability: Number of units (n) up to 8.



The concept's revenue model is designed to be two-phased (Figure 22). The first phase of the revenue model is the sale of the plant, which is a one-off transaction that is the customer's investment. The pricing is based on target costing that may vary slightly across different farms.

The second part of the revenue model is continuous revenue throughout the plant's lifecycle. This continuous revenue includes an on-going service fee for which remote control and optimization are included.

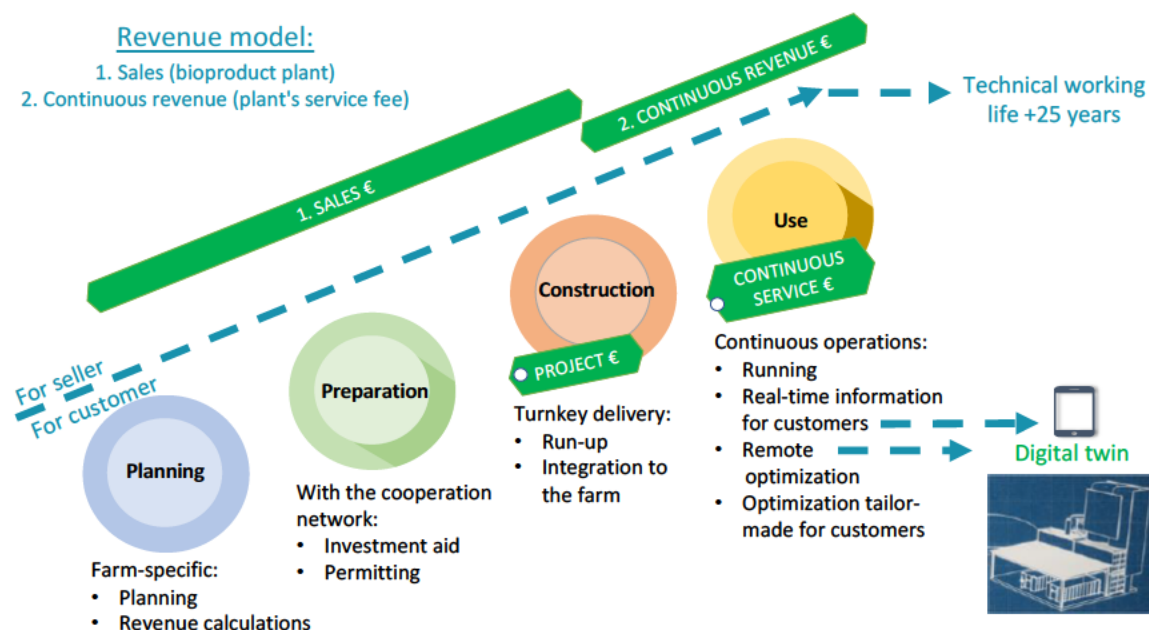


Figure 22. Bioproduct plant concept revenue and business model.

Different revenue models can also be explored. For example, a licensing model is a possibility for future revenue models, as it eases the investment load of the farmer and outsources the responsibilities to the company. A royalty-based revenue model is another possibility as it eases the production load from the company and transfers it to a bigger company with an already established production organization, subcontractor networks, and sales channels.



7.2. From the farmer's point of view

The bioproduct plant provides the farmer with multiple economic benefits (Figure 23). By producing four valuable bioproducts, the bioproduct plant can significantly boost a farm's profitability and self-sufficiency.

The economic benefits that the bioproduct plant provides include:

- Biogas into heat and electricity

This benefit saves the farm heating and electricity costs. On bigger farms, biogas could even be upgraded and/or refined and utilized either as a transportation fuel or sold to the grid.

- Liquid fertilizer and dry fertilizer for the farm

Saves on fertilizer costs by replacing purchased fertilizers. In addition, using the bioproduct plant's optimized fertilizers increases crop yield, which can bring extra revenue for the farmer from the crop.

- Sterilized bedding for the farm

Producing sterilized bedding in the process from the farm's own manure eliminates the need for purchased bedding. With a seller's permit, excess bedding could be sold from the farm, creating extra revenue.

- Bioprocess decreases the mass/amount of manure to spread on the field

This saves on manure spreading costs as there is less fertilizer to spread. The savings are estimated to be up to 6%.

- Saving of time in manure handling

The bioproduct plant does not consume the farmer's time but instead saves it by processing all of the farm's manure. The plant is designed to be fully automated, and it can be remotely controlled and optimized by the company.



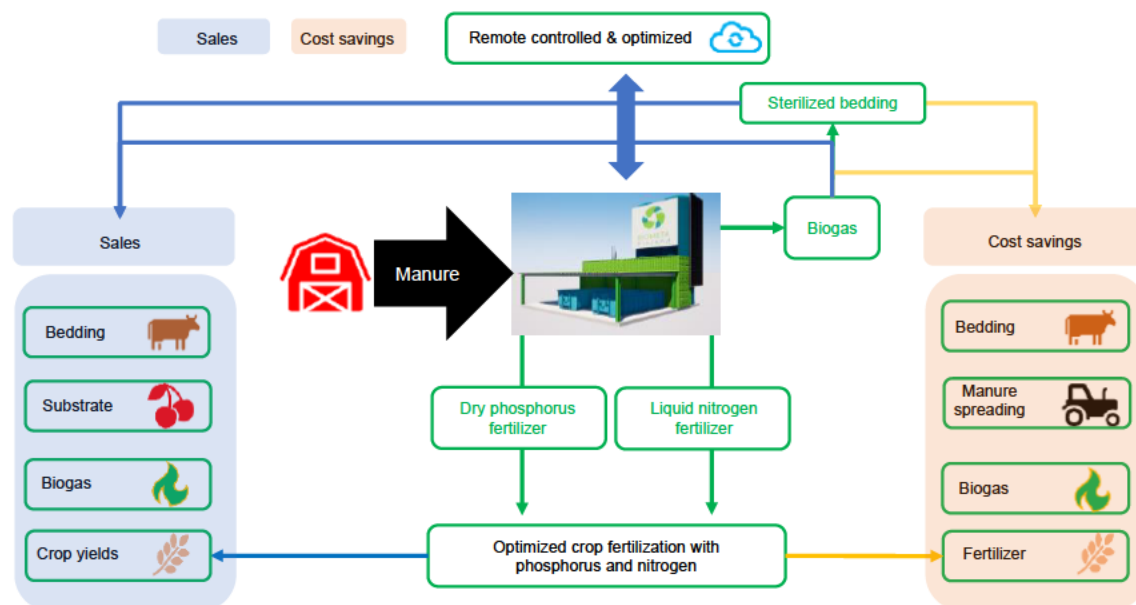


Figure 23. Bioproduct cycle on the farm.

Example calculation assumptions:

- Manure per year: 5 000 tonnes
- Crop: Barley
- Bedding usage: ~ 330m³ per year.

Table 8. Example calculation of economic benefits for a dairy farm.

Bioproduct	Benefit	Amount	Benefits, in EUR
Biogas	Heat/Electricity	Biomethane: 48 125 m ³ Heat: 216 500 kWh Electricity: 168 400 kWh	10 800 EUR 25 300 EUR
Liquid fertilizer	Fertilizing Effect	4600 t	18 500 EUR
Dry fertilizer	Fertilizing Effect	170 t	
Sterilized Bedding	Own Use/Sales	330 m ³	27 800 EUR
Manure Spreading	Less Manure to Spread	250 t	700 EUR
TOTAL			83 100 EUR

The target in the business development from the customer side is that the return on investment (ROI) or investment payback time is achieved in under 10 years. The ROI



varies across different types of farms, and depends on a multitude of factors, such as utilization of biogas, fertilizer situation, the crop the farm is growing and what type and how much bedding the farm uses.

For the customer, the process from the initial screening process to investing in the plant and operating it on the farm is done as easily as possible. Permit and investment aid processes are done in co-operation with network utilization.

Making the whole process as easy as possible is an added economic benefit of the bioproduct plant for the farmer – the saving of worktime that the plant provides. The plant is designed to be fully automated, remote controlled and optimized so that it does not consume the farmer's time but instead saves it.

7.3. Biogas Market

The market for biogas production is rising around the world. The market value specifically for biogas plants was worth \$3.1B in 2020, predicted to grow at 9.3% CAGR (compounded annual growth rate) to \$6.52B by 2028¹⁰. The overall market for waste-derived biogas was worth \$52.9B in 2020, growing at 8.5% CAGR, predicted to reach \$125B by 2030¹¹.

Farms everywhere are looking for solutions to boost their profitability; countries are looking to increase their self-sufficiency and there is a global ambition for solutions that can reduce emissions and be part of the green transition.

There is already a strong existing market for biogas plants. There are thousands of biogas plants in Europe and the rest of the world. However, most of the current plants are still suitable and viable for bigger farms only, leaving the small and medium sized farm segment market largely untapped.

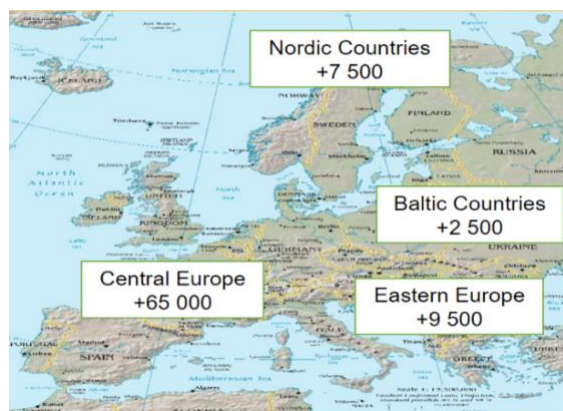


Figure 24. Results of Biometa's pre-sales study 1: The number of potential farms.

The bioproduct plant provides a solution for the small and medium farms as well and therefore enlarges the market segment and unlocks its full potential. Due to their smaller size and lower investment costs, a far larger number of farms can be included in the customer segment.



Given that only 10% of EU farm manure is currently processed, there is huge potential for installing new capacity to process the remaining 90%.

Based on Biometa's own pre-sales study 1, there are approximately 125 000 dairy farms in the EU that fit into the 50–500 head of cattle segment. In the 50–200 head segment, there are approximately 90 000 dairy farms, showing the huge potential of the bioproduct plant concept (Figure 24).

To test and scan the demand for, viability and suitability of the bioproduct plant concept, Biometa also conducted a preliminary customer survey in 2022. The findings were as follows:

- 97% of farms are looking for solutions that can increase their profitability and self-sufficiency
- 86% of the respondents considered the bioproduct plant solution to be beneficial for their farms.

The survey's results showed that there is a strong desire to utilize manure as a way to obtain more income for the farm and thus boost profitability and self-sufficiency.

There is a clear void and therefore potential for solutions like the bioproduct plant in the market. The number of dairy farms in Europe, which are the primary customers, is expected to change due to concentration in the sector. The numbers of small farms of 50–100 head are falling by 3.1% annually, as they close down or are merged into larger farms. However, the number of farms of 100–500 head will increase by 2.2% a year. The bioproduct plant is suitable for farms with up to 500 head of cattle. Even though the overall number of farms is slowly diminishing in Europe, this mostly concerns farms with less than 50 or 100 head of cattle. Therefore, the future outlook for the overall market segment is still strong.

8. Next Steps

The ultimate purpose of this white paper was to describe, explain and demystify the bioproduct plant innovation and show its global potential. We hope that with this white paper, the bioproduct plant innovation, its potential and benefits will be more broadly and easily understood.

To realize this innovation, we will:

- Offer this innovation to any interested parties who have the ability and willingness to commercialize it.

We will do this by:

- Providing Biometa's technical and commercial information and support to build the world's first farm-scale bioproduct plant.

Our technical and commercial information includes:

- the industrial rights and assets
- all engineering data including Mass & Energy balance calculations and Piping & Instrumentation diagrams
- all cost data and concept information
- all data from the simulations and the experiments
- Biometa's expertise.



9. Summary

This white paper presents Biometa Finland's bioproduct plant concept through technological, environmental, and economic lenses. The existing market was first reviewed and analysed with a comprehensive analysis of the current challenges in agriculture, current solutions in the market and their suitability.

The bioproduct plant offers a one-of-a-kind solution to the market. It is a solution that suits dairy farms (50–500 head per farm) that can bring significant economic benefits for the farmer while reducing harmful environmental emissions and effects. It handles all the farm's manure and turns it into four valuable bioproducts for the farm: biogas, dry phosphorus and liquid nitrogen optimized fertilizers, and sterilized bedding.

The bioproduct plant is a breakthrough process innovation that stands out from conventional solutions by utilizing a novel twin-reactor technology called HEGSB, which significantly boosts process efficiency and reduces reactor size, cutting investment costs. The process throughput is 3–5 times faster, 10–15 percentage points more efficient and has a 30–35 % lower energy consumption than conventional plants. Therefore, the bioproduct plant is a profitable solution for the company behind it as well.

The bioproduct plant can decrease a farm's GHG emissions in manure handling by 87%, and total GHG emissions by 25% per kilo of milk produced. In addition to GHG emissions, the bioproduct plant can also reduce the farm's manure ammonia emissions by 50% and COD (chemical oxygen demand) emissions by 60%.

On the whole, the bioproduct plant brings the bio-circular economy to the small and medium-sized farms for which there is no completely suitable solution at the moment. It is a profitable, environmentally friendly and time-saving solution for farms with up to 500 head of cattle per farm. It focuses on decentralized bioproduct production, instead of larger-scale centralized biogas production. The product concept is designed modularly, so it can be built locally and scaled globally.



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