FeBio: R&D of novel 75 kWel AD plant for difficult agricultural residues: horse manure, straw and green waste

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Abstract: Substrates for biogas production will be provided mainly by residues in future. Without a complex and expensive pre-treatment, solid residues with dry matter (DM) content higher than 30%, e.g. horse manure, husk, grass or straw can only be used in small quantities in a wet anaerobic digestion (AD) plant to maintain a DM content of lower than 15%. Especially for small quantities of dry and solid residues, typical for rural and agricultural areas, the application of small-scale dry AD-plants with a maximum capacity of 75 kW_{el} can be a technical smart solution. For solid residues, the dry AD process in combination with a Combined Heat and Power Plant (CHP)is technically favourable, as it works with DM content higher than 20% and provides electricity. The objective of the „FeBio“project (running time are 4 years, from 2020 – 2023 and funded by the German Ministry for Economic Affairs and Energy (BMWi) within the 7th Energy Research Programme) is the development of a small-scale dry AD plant for solid and stackable residues with low investment costs of 4,000 - 6,000 €/kW_{el} and electricity generation costs of lower than 18 €-Cents/kWh_{el}.

Keywords: biogas, straw, husk, grass, 75 kW, CHP, dry AD

1. Introduction

In 2020 biomass based fuels had the highest share of electricity production from renewable energy sources in Germany after wind energy (Agentur für Erneuerbare Energien 2021). The German government recognized bioenergy as one of the carriers for achieving the national climate goals and included the energetic use of biogenic residues and waste materials in the German Energy Research Program (BMWi 2018). As target substrates within the FeBio project, horse manure, husk or landscaping green are currently unused for biogas production due to high management costs by a.) decentralized distribution b.) locally small quantities. As typical wet AD-plants (the German “500 kWel standard AD-plant”), capable to use solid residues as co-substrate, can be found almost exclusively on dairy cattle farms. As these farms are distributed unequally across Germany, the economic use of solid residues is not feasible for wide regions of Germany. Nevertheless a potential for increasing the biogas production with these materials is seen for Germany (Baur et al. 2020) and internationally (Junginger et al. 2019).

The German legislature reacted to this fact with an increased remuneration for power and heat generation from 75 kW_{el} small-scale AD plants (Yang et. al. 2021). With regard to the utilization of excess heat, such small-scale systems have advantages compared to large systems, as only a few heat consumers, such as farm houses and buildings need to be available locally. Regarding environmental and climate protection, the farmers are motivated to cultivate meadows to use the grass cut as substrate for AD-plants (Noll et al 2020). As further aspect, the conversion of untreated horse manure to biogas and utilisation of the digestate as fertilizer reduced the negative impacts to water bodies by nitrogen and sulphur compounds (Tsachidou et al. 2021).

In order to reach the national goals and to expand the utilization of difficult dry substrates across Germany, the FeBio project wants to develop a possible solution with the help of an innovative small-scale dry AD plant.

2. Project “FeBio”

2.1. Background

Due to the increased entrepreneurial risk in the tendering process of the EEG 2017 (German Renewable Electricity Feed-in Tariff law) as well as the low remuneration success by the previous EEGs, the construction of larger AD plants has declined sharply since 2012 (Guss et al. 2016). This development prevented the innovation to valorise agricultural and livestock dry residues, which could not be used in the current AD-plant park due to economic, legal and technical reasons. According to Fehrenbach et al. 2019, these dry residues like horse manure, husk or landscaping green with up to 180 PJ primary energy content are generated in Germany every year. This substrate, identified by several research projects in the field of dry AD-plants (listed in FNR 2009), are difficult to use for biogas production and have so far only made up a small proportion of the total biogas substrates (FNR 2021). Especially horse manure is a problem in terms of disposal and it’s currently being used as fertilizer without pre-treatment.

Regarding the current wet AD technology solid and dry residues such as straw, landscape greenery, husk or horse manure can only be used in very small batches or must be pre-processed e.g. with a cross flow grinder (Mönch-Tegeder 2014). The investment of such cross flow grinders are uneconomical, especially for small-scale wet AD plants. Summarized, the economic feasible utilisation of those substrates in small-scale wet AD-plants inherit a cost problem, as more than 8,000 €/kW_{el} of installed power usually had to be invested for state-of-art AD technology. This is exactly where the “FeBio” project starts. The

project partner Ökobit GmbH has identified a dry AD plant concept which will generate significantly lower investment and operational costs, to bring small scale dry AD plants to the market as in large numbers.

2.2. Objectives of Project "FeBio"

The specific aim of the „FeBio" project (2020 – 2023) is the development of a dry AD plant for solid and stackable residues with low investment costs of 4,000 - 6,000 €/kWel (300,000 € to 450,000 € at 75 kW_{el}) and electricity generation costs of lower than 18€-Cents/kWhel.

The whole systemic "FeBio" concept delivers a marketable product with competitive investment and operation costs as well low specific GHG emissions. The target groups are organic vegetable (without liquid manure) or horse farms or regions with declining livestock with need of new pillar in agriculture and energy generation. The expected low investment costs go hand in hand with the robust technology, which greatly simplifies operation. Significant personnel costs can be saved by using auxiliary staff instead of costly technicians.

The project goals shall be reached by significant lower construction, transport and storage costs accompanied by a strong regional approach for input residues and output digestate. Critical issues are maintenance of environmental sound operation within legal settings.

During the construction and operation phases of the FeBio prototype deep knowledge of approval planning, operational experience and the overall project economic and ecological feasibility will be generated. Optimization measures e.g. for utilization of different substrates and different operating states (flexible and steady-state gas and energy production, full and part load, etc.) will be assessed and implemented continuously. Permanent documentation and evaluation of all project related processes and actions will secure the gained knowledge.

A patent of the system is aspired at project end.

2.3. "FeBio Dry AD-plant: history, design and features

The intended "FeBio" AD-plant is promoted by the company Ökobit GmbH. The system is based on a former prototype (Technical Readiness Level - TRL 6). The FeBio plant and will be set up in Saarland, in the city of Kirkel in 2021. The final plant shall reach TRL 9 in 2023 as a ready-to-market system.

Before the "FeBio" project, the development of the prototype was rejected by several banks due to its innovative character and the R&D classification in TRL 6. The existing prototype system delivered fundamental experience with regard to the challenges of such a system. Nevertheless, several technical parts were identified in need of optimization. Such optimization are subject to the "improved" system, which will be erect within the FeBio project.

The "FeBio" system shall be simple and of high-quality technology but implemented as a standardized structure (rectangular digester) by conventional construction companies to generate a cost-effective solution.

The total designed area of the project plant is about 5,000 m² and consists of the digester bodies including gas buffer tank, the substrate and digestate storage, an office building, a percolation water tank (ca. 25 m^3 capacity), a 75 kW_{el} CHP, emergency flaring system and working space for staff and machinery. The digester system itself (see figure 1) consists of three digester bodies with a capacity of 360 m^3 each (8.8 m x 20 m in a rectangular shape) and covers 1,100 m² space in total. The digesters are below the surface for easy loading and unloading as well as restrain of any digester water (see figure 2). The size of the digester is suitable for a wheel loader. The necessary water with the anaerobic bacteria is circulated via a pipe system, which is attached on the digester membrane. The weatherproof and gas-tight membrane works two-functional as gas storage and outer skin.

Figure 1. Pictures of original prototype digester bodies

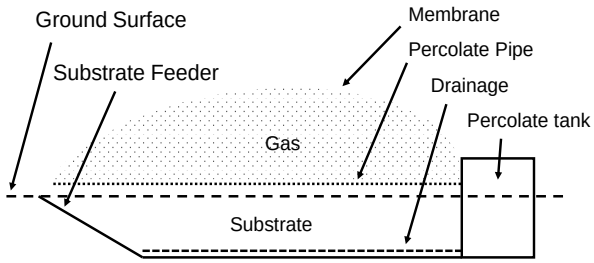

Figure 2. Cross-section of original prototype

The AD-process engineering is designed as batch process. Each digester is fed every third week with fresh substrate. During this procedure, a third of the digestate is being exchanged with fresh substrate. Totally, the substrate does ferment 9 weeks before being removed. Before opening of the digester, e.g. for substrate exchange, maintenance, etc., the biogas is sucked out into a gas tank. The plant is designed to operate at temperatures of ca. 40 °C (thermophilic conditions). Due to the low water content of substrate and no additional need of process water as for wet AD, a small-scale heating system is sufficient to maintain the adjusted temperature. The process control system comes as systemic solution and monitors the main process parameters such as temperatures and pressure in the digester bodies, the CH_4 content of the biogas, digester body pressure and the pH of the substrate. As main devices the heating system, the pump for the percolate and the biogas as well as the emergency flare need monitoring and controlling. The attached biogas CHP is designed as container solution and can be connected to the process engineering.

2.4. "FeBio"-plant in comparison to other systems

There are currently only about 700 small-scale biogas plants in Germany in operation (Bundesnetzagentur 2019). Due to the legal requirements of minimum use of liquid manure and slurry, small scale wet AD-plants had prevailed, therefore this type of systems are only interesting to dairy farmers, as they are restricted technically to a DM content of lower than 15%.

Substrates with high DM content, such as horse manure or greenery need mechanical pre-processing of the substrate with significant higher operational costs. Another reason for the low prevalence of small AD-plants is the high investment cost of € 5,300 to € 8,000 per kWel (KTBL 2013). A contributing reason for these costs is the operation as batch process, giving dry AD-plants a lower performance than for wet AD-plants.

For dry AD-plants small scale garage digesters are primarily used as solutions. Those plants have higher investment costs and GHG emissions than membrane covered systems as the "FeBio" plant.

Due to the technical requirements of the wet AD plants, residues with a high lignin content or a coarse structure are particularly difficult to recycle. These can only be fed into the process by means of an upstream comminution, so that (i) the energy potential of the substrate is used as much as possible and (ii) there is no technical disruption (clogging, floating layer). Alternative dry/garage digesters have a higher GHG releases due to temporarily opening and closing procedure as well as a higher specific construction costs compared to wet digesters. As advantage of dry AD plants, the electrical energy demand is less, as pumping, stirring or processing of viscous materials is not necessary. For example, for conventional wet AD process with a DM content of 20%, the energy consumption is 15% of the produced energy, with the FeBio system designed to be lower than 3%.

Table 1 shows current small scale Dry AD-plants providers in Germany. These commercial systems are characterized by a large number of differences from the applied FeBio system. The most important points are the high investment costs and that no market status (TRL 8 or 9) of any system has yet been achieved.

Table 1. Small Scale (75 kW_{el}) dry AD-systems providers Germany 2020

Type of System	Company	Homepage	Remarks
Container	Mineralit GmbH	http://www.mineralit.com	- Polymer Concrete Body - Highly engineered
Garage Digester	Renergon GmbH (CH)	http://www.renergon.ch	- Patented biogas re-circulation system
Garage Digester	Enbion GmbH	http://www.enbion.de/	- recirculation of percolated water - 40 - 190 kWel
Garage Digester	Pöttinger (A)	http://digester.poettinger-oneworld.at	- input of 1.000 - 5.000 t/a - optimised for organic residues
			- small size (3 digester + control-unit = 500 m²

2.5. Project Hypotheses

The FeBio system should show the following advantages in comparison to garage dry AD plants. These hypotheses are subject to assessment and evaluation within the project.

Target Substrates: The garage digesters are mainly used for biowaste recycling. The FeBio-project aims on application of bio residues and side products within the agricultural sector. As for the dry AD process liquid manure is excluded as substrate, a particular challenge is therefore the availability of 80% solid manure as substrate input to guarantee the requirements for the remuneration of small systems, defined in the German Feed-In Tariff law "EEG"[1].

Costs: Due to the removable membrane the digester body walls are very low and as the membrane functions as cover, no concrete roof is required. This concept also eliminates the need for a heavy and technological complex garage gates. This cost-intensive component is often a weak point in conventional garage digesters, where gas leaks often occur. The lack of a solid roof also enables the reactors to be pit-shaped. This simplifies the structural design of the structure, thanks to the supporting soil.

No ventilation: Before changing the substrate in a conventional garage digester, the biogas must be released. This action costs time and requires measurement technology e.g. to detect the gas concentrations. In the FeBio digester, the collected biogas is pumped out into a flexible gas storage tank. This process is optical visible and finished, if the membrane lies on the substrate.

Gas storage tank: As the membrane acts as a gas storage, an external gas storage, is not required.

Less air entry: As the gas membrane lies directly on the substrate, air entrapment and corresponding interruption of anaerobic processes is minimized. Implementation and operation of technology for active vacuuming of the digester is not necessary.

Opening/closing the digester: During the digesting process the solid organic substrate decomposes and loses its structure, making it more liquid do to release of cell water, The formerly stackable matter is more viscose and is moving due to gravity. In a garage digester, the substrate presses against the gate which needs reinforcing on door, frame, hinge and lock to withstand those forces. Further, while opening, the substrate can flow out and contaminate the working area. The pit shape of the FeBio digester avoids these problems. An opening of the membrane cover is possible in every operating state.

Machinery: The FeBio digester can be driven on with machines of all common sizes. Due to open design, health hazard from exhaust gases are not present.

Hazards: Due to the contraction design of the digester bodies and technical features to remove biogas into an external gas tank before opening, health and explosion hazards from biogas are not present. The applied

[1] Erneuerbare Energien Gesetz

percolate system is designed to use low amount of water to minimise water pollution and consumption.

End-of life use: The FeBio digester can be converted into other agricultural services at the end of designed life time or other events. This potential represents a strategic advantage in case biogas production is terminated.

Energy and GHG-Performance: The "FeBio" digester shall operate on lower self-energy demand (electricity and, above all, heat) than wet AD plants application of a small-scale heating system and the total elimination of a substrate mixing device and pumps for additional process water. This creates higher net power output for e.g. flexible operation purposes. In addition to the plant operation, the supply of substrates is also a decisive point that has an impact on the economic efficiency and the CO_2 balance.

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