Deutsches Biomasseforschungszentrum
gemeinnützige GmbH

Technical Overview

RESEARCH & DEMONSTRATION PLATFORM

Innovation | Research | Development

Content

Introduction

The pilot plant was planned, constructed and commissioned at the DBFZ site as part of the Pilot-SBG research and demonstration project. The use of agricultural residues and municipal waste will be demonstrated in initial test campaigns.

The integrated, automated and digitalised plant concept combines both established and innovative technologies. It can process biogenic residues, by-products and waste to produce renewable methane as the main product using green hydrogen. Thanks to its modular design, it can not only be flexibly combined and expanded, but also optimally integrated into the DBFZ‘s research infrastructure and expertise:

1. Process engineering research and development builds upon the scaling of the individual processes, which have already been established in multi-stage scaling at a smaller laboratory and pilot plant scale at the DBFZ. The process technology expertise at the DBFZ provides a solid foundation for potential expansion modules and the continued development of the research and development platform.

2. Data acquisition and processing enable real-time measurement of parameters and process monitoring through extensive measuring points. This capability is supported by the DBFZ´s comprehensive analytics portfolio, which leverages its in-house laboratories. The robust data foundation facilitates iterative, real-time process optimisation and serves as the basis for modeling and simulating a digital twin. This digital twin enables the integration and advancement of AI-based process control. Additionally, the resulting mass and energy balances underpin the technical, economic and ecological assessments.

3. The multi-criteria **assessment of supply** chains includes not only an ecological evaluation focussing on greenhouse gas emissions but also an analysis of cost-revenue structures in the context of existing and foreseeable framework conditions. This approach identifies optimization potential not only for individual processes but also for interfaces and interactions within the process chain. Upstream and downstream stepssteps, which are not directly demonstrated at the pilot plant, are also analysed with a view towards potential implementation on a commercial scale.

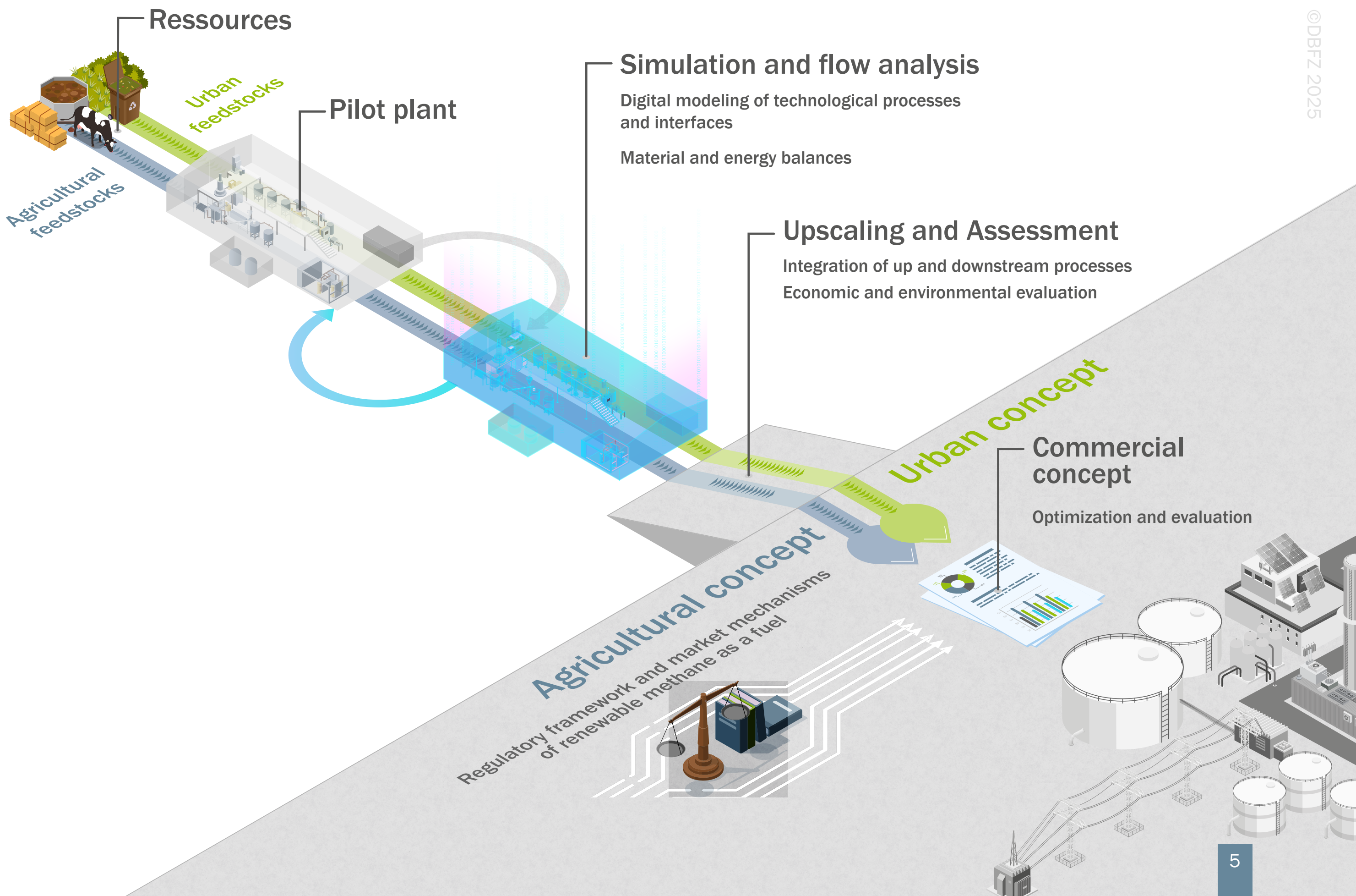
4. The system integration of the concepts involves contextualising the results. The broad expertise of the DBFZ team allows for addressing questions related to mobilisation of the resource potential or integration of renewable hydrocarbons into existing infrastructure. The focus is on advancing and integrating the concept to contribute to a cross-sectoral sustainable bioeconomy and to provide high-quality co-products based on potential demand and market developments.

The pilot plant intended to evolve into a central component of an R&D technology platform for further research and development projects with industry and scientific partners. The high flexibility of the plant regarding the addition of new, innovative modules and the ability to detach individual plant components from the process chain and to operate them separately, is an advantage. Furthermore, the integration within the DBFZ enables the comprehensive evaluation of promising technical innovations supporting market integration and making a meaningful contribution to the defossilisation of products.

Project lead

Philipp Knötig
& Karin Naumann

Team Pilot-SBG



Pilot plant – R&D platform

The pilot plant incorporates a combination of state-of-the-art and innovative processes, including methanation, anaerobic digestion (AD), hydrothermal processes (HTP) and several separation units. It is an integrated, intensely monitored and highly automated plant, that is operated in a 1000 m^2 experimental area at DBFZ in Leipzig. The system´s modular design allows for flexible operation, enabling various processes to be combined seamlessly or operated individually. Additionally, the plant is designed to accommodate the integration of new technologies, which can be operated either continuously as part of the entire system or independently within individual modules. The robust design of the existing technology supports the use of a wide range of raw materials. Currently, the plant processes residual and waste materials such as wheat straw, cattle manure, green waste and biowaste. The interconnected modules are configured to create a biorefinery concept aimed at producing renewable methane and value-adding by-products (fertilizer, hydrochar, etc.). With the addition of new technologies, the product range can be expanded accordingly. Potential target products could include methanol from biogas and carboxylic acids from fermentation residue.

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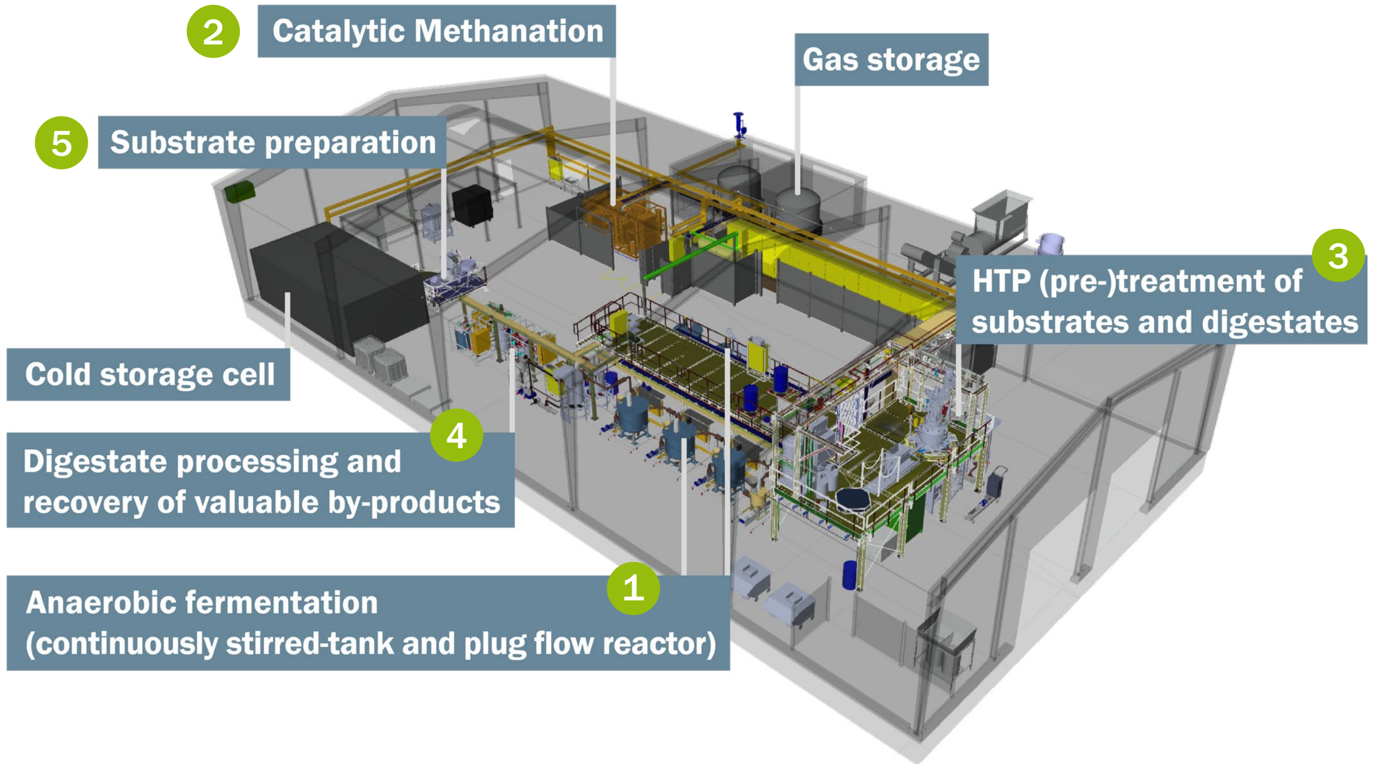
We are interested to get in touch with potential partners (research, industry) and other stakeholders,

...to create new projects to develop robust and economically feasible biorefinery concepts,

...who want to test their innovative technology within our existing environment

...who want to use individual modules for their own research and development projects.



1 Anaerobic fermentation

During fermentation, the processed biomass is broken down by microorganisms in a controlled process under the absence of oxygen and at a suitable process temperature. The decomposition of organic matter introduced into the reactors produces biogas, a mixture of mainly methane and carbon dioxide. For this purpose, the research and demonstration platform provides two separate reactor lines with three digesters each. They differ in their first stage digesters and their mode of operation and maximum dry matter contents of the substrates. Hence, this technical setup allows for a direct comparison of the reactor systems, the biogas qualities and quantities of each digester stage and the influence of hydrothermal pretreatment on the substrates. Considering economic and ecological aspects, the analysis of methane yields over the process stages serve as a planning basis for process scaling and identification of operating points. For the latter, a compromise between substrate utilisation and costs has to be identified.

Technical Data

2 Reactor lines (RL)	5 identical continuously stirred-tank reactor reactors (CSTR), 1 plug flow reactor PFR) RL 1 in series with main digester (CSTR), post digester (CSTR) and digestate storage (CSTR) RL 2 in series with main digester (PFR), post digester (CSTR) and digestate storage (CSTR) Volume: CSTR 1000 L, PFR 500 L Material: stainless steel (V2A) Inner gas pressure (rel.): –15..15 hPa Temperature: 25 – 70 °C
Gas storage	Central gas storage Volume: 6 m³
Gas analysis	quantitative for each reactor, qualitative: CH_4, CO_2, H_2S, O_2
Additive addition	one peristaltic pump per line connectable to each digester

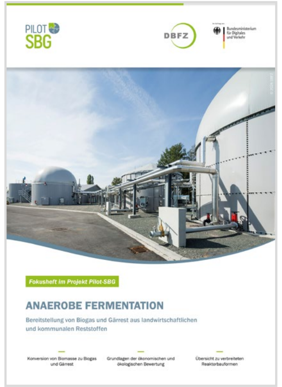
How biogas is produced

Anaerobic digestion is a worldwide well-established technology for energy recovery and treatment of organic waste streams. In either case, energy in the form of biomethane is provided, which can be utilized in numerous ways (e.g. CNG, LNG, grid injection, on-site CHP). The solid remainder of the process – the spent substrate or digestate – can be directly used as a fertilizer or undergo further processing for the recovery of added-value products.

A unique feature of the research and demonstration platform is the modularity of the digesters. It allows for direct comparison of different reactor types at given operating conditions and substrate characteristics. For the former, amongst others, different substrate pretreatments, process temperatures or additives can be compared. For the latter, novel organic substrates or their combinations can be tested for their suitability in the reactor systems available.

Furthermore, due to the modular layout of the two fermentation lines with three digesters each, various digester configurations in terms of subsequent or parallel process stages can be realized. Available reactor types are currently five continuously stirred-tank reactors (CSTR) and one plug flow reactor (PFR). As each of the reactors is mounted on an individual rack, these six reactors can be interconnected as required by the research purpose – allowing for testing several process stages or investigations in parallel.

CSTRs are the prevailing digester type in agricultural application and are commonly used for pumpable substrate streams with a dry matter (DM) content of ≤15 %. PFRs however are capable of digesting input streams of ≤45 %. Therefore, and due to their lower susceptibility to impurities, PFRs are the most common continuous reactor system in organic waste treatment.



Anaerobic fermentation

Provision of biogas and digestate from agricultural and municipal residues

DOI: 10.48480/b9vn-9686
ISBN: 978-3-949807-09-1

[German version]

2 Catalytic methanation

Biogas from two digesters is extracted, purified and converted to methane (CH_4) by methanation to meet DIN EN 16723-2 fuel standards. The biogas is first cleaned at ambient temperature and without pressure using adsorbents such as activated carbon or metal oxides to remove harmful components, particularly hydrogen sulphide (H_2S) and other sulphur-containing molecules. The gas is then compressed to 20 bar, heated to 150 °C and passed through a police filter to remove residual H_2S.

In the second stage, hydrogen (H_2) is added to the biogas, which reacts with carbon dioxide (CO_2) in the methanation reactor to form methane. The H_2 dosage is adjusted according to the CO_2 content of the gas. The gas is then depressurised and cooled to condense and separate the water produced during the reaction. Finally, the remaining CO_2 is removed in a two-stage caustic soda scrubber to produce high purity methane suitable for use as a fuel.

Technical data

Methanation reactor	Volume: 570 ml Pressure: max. 25 bar Temperature: max. 420 °C Three zones with electric heating Three zones with air cooling
Product gas	Produced quantity: 2,47 m^3/d Methane content: > 95 vol.-%
Adsorption vessel	Two identical vessels Integration in series or single Volume: 73.6 L (per adsorption vessel) Atmospheric pressure Ambient temperature
Gas analysis	Device: Inficon µGC (on-line) Quantitative: CH_4, CO_2, H_2, CO, N_2, O_2, C_2H_6, C_2H_4, C_3H_8, C_3H_6, C_4H_{10}, C_4H_8, H_2S
Technical gases	Separate operation with technical gases possible (CH_4, CO_2, H_2, N_2, CO)

The methanation reactor is a tubular reactor with an internal diameter of 26.9 mm. The catalyst is in the form of a fixed bed through which the reaction gas flows. Inside the fixed bed is a multipoint thermocouple to measure and monitor the reactor temperature over the length of the reactor. The reactor is divided into three temperature zones, in which the desired reactor temperature can be set individually by electrical heating. Elevated temperatures or peaks due to reaction heat are prevented by automatic air cooling around the reactor.

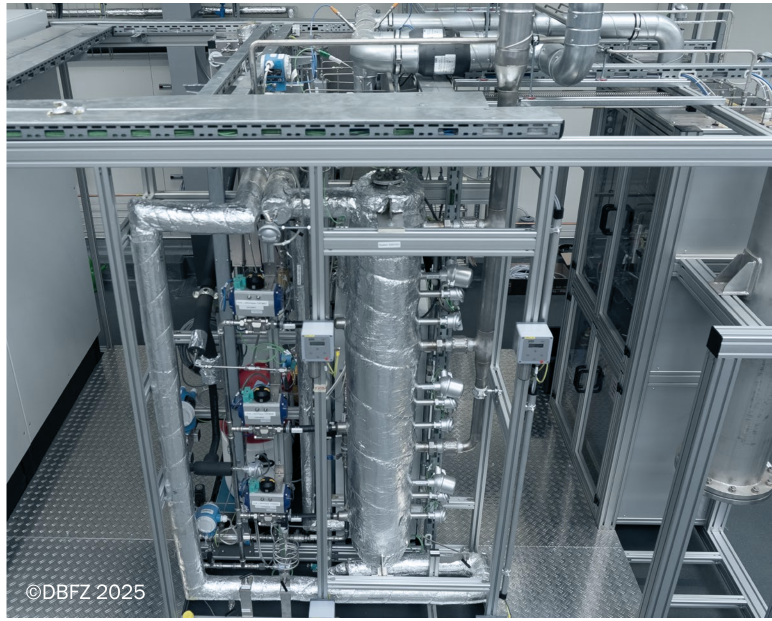
In addition to normal operation with biogas, separate operation with technical gases is also possible. Methane (CH_4), carbon dioxide (CO_2), carbon monoxide (CO), hydrogen (H_2) and nitrogen (N_2) are available as pure gases, which can be individually mixed via a control system and fed into the reactor.

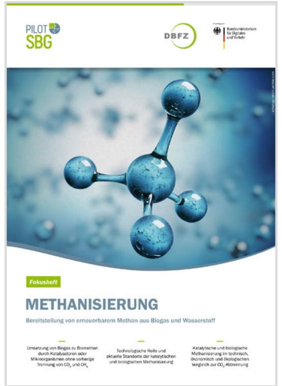
Application options

In addition to the normal operation with real biogas, the catalytic methanation is equipped with a control system for the use of technical gases, which can be used for operation with defined educt gas compositions. This allows new catalysts to be analysed with a high degree of comparability on a relevant scale. In addition, measurement data can be generated quickly for any biogas composition without the need to supply large quantities of biogas with a long start-up process. Variations in biogas composition can also be taken into account. In addition to methanation, which is currently being investigated, other catalytic gas-phase reactions could potentially be investigated in the reactor, considering pressure and temperature limits.

Furthermore, the catalytic methanation module offers the possibility of coupling with other upstream processes that provide a gas suitable for methanation via a few well-defined plant limits. The high degree of automation and the many options for adjusting the process conditions make the plant suitable for carrying out long-term tests and parameter studies.

Additionally, the possibilities of the pilot plant can be applied for the investigation of other processes for the use of biogas as feedstock for chemicals production.





Methanation

Provision of renewable methane from biogas and hydrogen

DOI: 10.48480/rm3g-ej31
ISBN: 978-3-946629-99-3

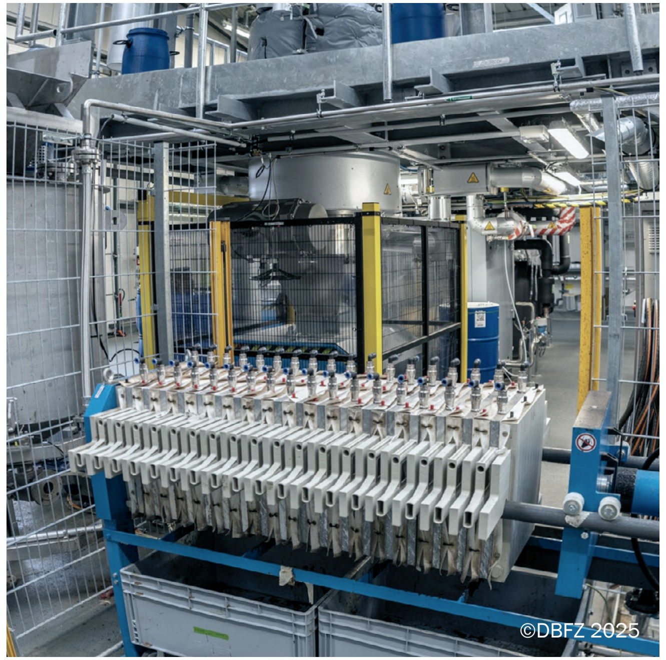
[German version]

3 Hydrothermal processes

The hydrothermal processing unit's center piece is a 500-L stainless steel reactor. It is used to pre-treat complex biomass for the anaerobic fermentation and to post-treat the digestate. Key features of the system include a unique near-wall and coil-shaped stirrer to handle a wide variety of real biomass with a dry matter content of up to 25 %. Further, a steam generator allows for a considerable heating rate of up to 2 K/min despite the large volume. Close process monitoring enables precise reaction control and balancing while treating biomass at conditions up to 240 °C and 40 bars. At these elevated conditions, the polymeric biomass constituents are hydrolyzed to their monomers, which decompose and recombine to form hydrochar and water-soluble products. At lower temperature and shorter reaction time, this can be utilized to break down the lignocellulosic matrix making the biomass more easily accessible and better digestible for the involved microorganisms in anaerobic fermentation yielding more biogas in less time.

Technical data

Nominal volume	500 L
Working temperature	Up to 240 °C
Working pressure	Up to 40 bar
Heating rate	Approx. 2 K/min
Material	Stainless-steel 316
Maximum agitator torque	8000 N m
Highlights	• Optional process-integrated steam injection • Spiral agitator fitted close to the wall for handling real biomass • Input screw • Double jacketed reactor with active cooling



Pre-treat & carbonise

Feeding

The biomass or digestate is collected in barrels and transferred into the feed container. A screw conveyor, able to handle dry and fibrous materials and sludges, feeds the mixture into the reactor. The reactor is tightly closed and the reaction is ready to start.

Hydrothermal reaction

Temperature and reaction time depend on the type of material and its use afterwards. For pretreatment, comparatively low severity is employed. The main goal here is to hydrolyze the biomass to improve the biogas yield and kinetics afterwards. When using digestate, harsher reaction conditions are used to carbonise the material and obtain a hydrochar. After the reaction, the product can be cooled actively using the thermal oil in the jacket.

Product utilisation

The product mixture is obtained by opening the ball valve at the bottom. Depending on the use case, it is either fed to anaerobic fermentation or can be sent to posttreatment to purify the process water and separate the hydrochar. The hydrochar's high nutrient and carbon content open possible usage paths, such as soil application or carbon capture, utilization and storage.

▶▶▶ *Mechanically and thermally dried hydrochar*

Hydrothermal processes

Hydrothermal processes (HTP) enable diverse and attractive applications. HTP can efficiently convert biomass – and in particular highly-wet, biogenic residues and waste materials – under increased pressure and temperature into high-quality refined solid, liquid or gaseous carbonaceous products. A large variety of starting materials can be used to make a wide range of products available. Thus, HTP sustainably contribute to resource protection and are an essential component of a future bioeconomy.

Visit the webpage to explore how hydrothermal processes are turning waste into valuable resources and paving the way as part of a sustainable future!

www.dbfz.de/htp

5 Substrate preparation and storage

The module's task is to prepare the raw input materials for the test operation and to store them. It consists of crushing techniques, mixing systems and a storage unit with cooling. The compartments are used to condition the raw materials, such as straw and biowaste, to reduce the particle size to a usable condition in the research facility.

The conditioning of the input materials is necessary for the applicability in the storage container, the eccentric screw pump and the following piping system.

Another component of the substrate preparation and storage unit is an ultrasonic disintegration device. This allows for a further break down of the substrate through the process and optimises the methane output.

The coolable storage system provides the possibility to store raw and already conditioned substrate over longer periods, especially for the weekend operation. Cooling avoids the change of the substrate for a more predictable substrate supply.

Technical data

Equipment	Performance, throughput
Straw mill	14.7 kW, 100 – 2000 kg/h
flail shaft shredder	3.5 kW, 640 kg/h
blade shredder	2.8 kW, 200 kg/h
cement mixer	0.9 kW, 250 L (total capacity)
ultrasonic disintegration	1.5 kW, >1000 L/h

Preparation and conditioning

The substrate pretreatment module plays a critical role in optimising organic waste for biogas production by ensuring that the feedstock is in an ideal condition for the anaerobic digestion process. It is designed to prepare the biomass, adjusting key factors like particle size, fiber length and dry matter content. This ensures that the substrate is sufficiently processed to avoid operational disruptions and to maximise the efficiency of the biogas plant.

Substrate preparation and processing stages

Particle Size and Fiber Length Adjustment: The module works to reduce the particle size and fiber length of various biomass types (e.g., cereal straw, green cuttings, biowaste) to below 20 mm. This step is crucial as finer materials provide a greater surface area for microbial degradation, thereby enhancing biogas production. Dry Matter Content Control: in this module the dry water content of the substrate mixtures gets adjusted before in. Proper moisture content is vital for the subsequent anaerobic digestion process, as it influences the microbial activity and efficiency of gas production.

Diverse biomass treatment

Given the variety of organic wastes, such as coarse straw, fine green cuttings or moist biowaste, different processing steps are required to ensure that each material is prepared appropriately.

Coarse, fine, dry and wet comminution

The pretreatment process includes different stages of comminution (breaking down the biomass into smaller pieces) based on the material's specific characteristics. For example, coarse materials like straw might undergo more intensive grinding, while moist or green materials might be shredded or chopped to achieve the desired consistency.

Modular design with batch operations

The pretreatment system is not a single unit, but rather a combination of different aggregates that work in batches. This allows for flexibility and adaptability, as each biomass type can be processed independently to achieve optimal conditions for digestion. The batch system allows for ongoing operation, with each type of waste being processed as required without interrupting the overall system's operation.

Central weighing station

A centralised station is used for accurate measurement and monitoring of the feedstock quantities, ensuring consistent and proper dosing of materials into the system. This station is crucial for maintaining the right balance of biomass in each batch.

Filling, transferring and mixing areas

Once biomass is processed, the system includes dedicated spaces for filling, transferring and mixing the substrates. This ensures that the batches are homogeneous and ready for the next steps in the biogas process.

Batching for storing and conveying

One of the key goals of the module is to produce substrates that are storable and easily conveyable. By adjusting particle size and moisture content, the pretreatment ensures that the substrate remains in an optimal condition for storage before entering the next phase of the biogas production process. The resulting batches can be easily transferred to the digester, where the anaerobic digestion will take place, without causing blockages or operational issues.

The influence of comminution along the fermenter section could be of interest to research institutions as well as to practical users. The rheological properties and the change in methane output in this kind of setting has not been researched in detail. The substrate preparation and conditioning is used to make the raw input materials suitable for the research facility and offer no innovative features itself. The experiences from the experimental operation can be used for a later scale-up.

Substrate preparation

Optimising the degradation of high-fibre biomass for the biogas process

DOI: 10.48480/9q7a-py77
ISBN: 978-3-949807-17-6

[German version]

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5 Digestate treatment

The digestate treatment module is a multi-stage system, that processes and valorises by-products from anaerobic digestion. This process produces dischargeable water, a solid organic fertilizer rich in nitrogen and phosphorus and a liquid inorganic fertiliser rich in nitrogen and potassium. During the process, all relevant process parameters are recorded to monitor the separation processes and determine mass and energy balances. The module operates as a separation cascade, with each stage further processing the digestate. Mechanical separation removes coarse solids first, while subsequent steps target finer impurities and dissolved compounds. This approach ensures efficient resource recovery, reduces waste volumes and helps meet environmental standards.

A key feature of this module is its flexibility, allowing it to adapt to different feedstocks or system goals. The module's design promotes a circular economy by recycling nutrients and recovering water for reuse or safe discharge. It also prevents potential issues associated with the direct application of raw digestate. By converting waste streams into useful products, the module demonstrates a sustainable approach to waste management.

From digestate to water and nutrients in four steps

This digestate treatment module comprises four main steps. Each step targets specific components in the digestate stream.

Initial dewatering

A screw press or chamber filter press removes coarse solids. This step produces a solid fraction with 20 – 40 % dry matter, while the liquid fraction passes on to the next stage.

Decanter centrifuge

Decanter Centrifuge separates fine solids from the liquid. This step is critical for reducing the total suspended solids in the liquid stream, thereby enhancing the efficiency of membrane-based processes. The concentrated sludge is typically used as a nutrient-rich amendment for agricultural purposes.

Ultrafiltration (UF)

UF employs ceramic membranes with a pore size of 100 kDa, ensuring the removal of fine particles and pathogens. The resulting permeate is low in suspended solids and organic load, making it suitable for further treatment through reverse osmosis. The concentrated retentate is either recycled back to the digester or disposed of, depending on the operational strategy.

Reverse osmosis (RO)

As the final step in this module, RO purifies the permeate from UF. RO uses high-pressure membranes to remove dissolved salts and micro-pollutants from the liquid. It produces high-quality water that meets environmental discharge standards. This clean water represents about 50 % of the original digestate volume. The concentrated retentate can be recirculated to the anaerobic digestion or used as liquid fertiliser.

Each stage is modular and adjustable allowing researchers to integrate or bypass certain steps to match specific study goals. Operators can also test new materials or evaluate different operational scenarios. Real-time sensors record critical parameters and this data helps fine-tune performance and maximise resource recovery. The flexible configuration of the pilot plant enables users to test laboratory findings on a larger scale and supports the development of new nutrient recovery methods or water reuse strategies.

Digestate treatment

Separation processes and technologies

[German version]

Technical data

Screw press

Throughput	15 m^3/h
Operation mode	discontinous
Material	stainless steel
Mesh size	0.5 mm
Engine	2.2 kW
Cleaning time	30 min

Ultrafiltration

Molecular weight cut-Off (MWCO)	100 kDa
Possible yield	90 – 1200 L/h
Membrane	ceramic, 19 channels
Membrane area	3 m^2 (12 filter elements, each 0.25 m^2)
Channel diameter	3.3 mm

Decanter centrifuge

Throughput	5 – 100 L/h
Max. acceleration	4400 g
Max. speed	10000 U/min
Differential speed	1 – 200 U/min
Engine	2 x 3.5 kW
Material	1.2471 (315 Ti)

Chamber filter press

Throughput	0.65 – 0.7 m^3/h
Operation mode	discontinous
Chamber volume	74.9 L (17 chambers)
Plate size	470 x 470 mm
Drive type	electric hydraulic unit, pressure pump
Engine	1.5 kW
Filtration pressure	16 bar

Reverse osmosis

Throughput	100 L/h
Membrane length	1016 mm
Membrane area	2.8 m^2
Operating pressure	63 bar
Highlights	salt retention
Motor power	1.5 kW
Filtration pressure	16 bar

Contact & Imprint

Pilot plant for renewable methane

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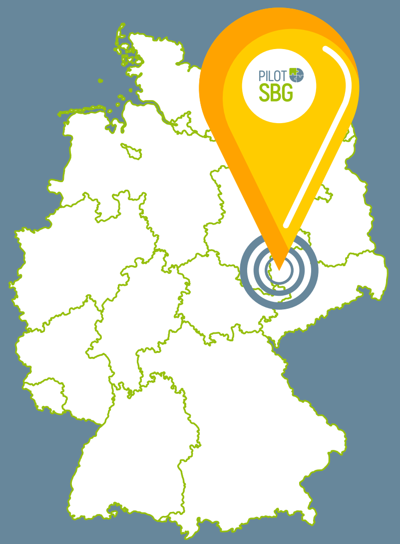

More information about the research project, pilot plant, renewable methane and our publications:

www.dbfz.de/pilot-sbg

PILOT SBG

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RENEWABLE FUELS

On behalf of:

Federal Ministry
of Transport