Decarbonizing sugar production with biogas and biomethane: Alternative approaches and engineering solutions in practice

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1 Introduction

The sugar industry is undergoing a profound transformation as it works to reconcile energy-intensive production with climate targets, rising energy costs, the need for competitiveness, and sustainability. Biogas and biomethane (renewable methane produced through biogas upgrading) are among the most effective solutions to support this transition. The traditional approach to the engineering and operation of biogas plants prioritizes process stability, as methane-producing bacteria prefer consistent feeding conditions. On the feedstock side, this is typically achieved by storing organics from the sugar industry to ensure a stable daily supply to the biogas plant. While this approach provides a steady energy output, it does not align with the sugar industry's seasonal energy demand profile. In the conventional concept, the produced biogas is upgraded to biomethane and injected into the natural gas grid. Biomethane is in high demand and, in addition to its environmental benefits, provides a stable and predictable revenue stream for plant owners. However, biogas upgrading to biomethane is energy-intensive, and the economic feasibility of such projects has traditionally depended on long-term biomethane purchase agreements. The new biogas plant for the sugar industry in Poland introduces an alternative approach: an 8500 m^3/h (S .T.P.) biogas facility designed to operate on a seasonal basis, delivering energy in the form and at the time required by sugar manufacture. Whenever possible, biogas is used directly in the sugar plant's steam boiler, replacing fossil gas; any surplus is converted into biomethane and injected into the national gas grid. This plant is the latest tailor-made engineering project for the sugar industry by Krieg & Fischer Ingenieure GmbH. The company started engineering biogas plants for the beet sugar industry 15 years ago. With plants in the Netherlands and Germany that have been in operation for more than a decade, the new plant in Poland that is now in its first beet campaign, and several ongoing projects, the engineering team of Krieg & Fischer Ingenieure presents a range of approaches from

their practice and different technological options available to the sugar industry nowadays.
The aim of this article is to analyze practical solutions for biogas and biomethane plants in the sugar industry, reflecting the different approaches and priorities that have been defined as tasks for engineers. By summarizing these experiences from engineering practice, the article should improve the foundation for informed decision-making by potential investors, while contributing to the ongoing development of the biogas sector. Ultimately, the choice among different solutions rests with the investors, guided by strategic objectives and operational performance.

2 Benefits for the sugar industry

Biogas and biomethane offer a unique combination of environmental, economic, and operational advantages that align directly with the industry's sustainability priorities.
Sugar production requires substantial thermal and electrical energy, traditionally generated from fossil fuels such as natural gas, coal, and fuel oil. These energy sources are becoming increasingly expensive and highly volatile in price. Sugar companies are exposed to energy supply bottlenecks and significant price fluctuations, as well as to growing regulatory pressure – particularly due to rising CO_2 emission certificate costs. By switching to biomethane, sugar producers can significantly reduce their dependence on fossil fuels and transition to renewable energy sources, taking a decisive step toward climate-neutral production.
Sugar producers are actively pursuing ambitious decarbonization strategies in both manufacturing and sugar beet cultivation, intending to reduce absolute greenhouse gas emissions from their facilities. As central pillars of these strategies, biogas and biomethane enable CO_2-neutral sugar production to become a realistic and achievable target. Many producers have already defined clear milestones – such as halving CO_2 emissions by 2030 and achieving full carbon neutrality by 2050 – with biomethane positioned as a key lever for reaching these goals.
Biomethane is also a product in strong demand. By producing biogas and upgrading it to biomethane, sugar producers not only reduce their exposure to energy market supply bottlenecks and price volatility but also gain the opportunity to sell biomethane at stable and attractive prices, creating an additional and predictable revenue stream.
Finally, biomethane production is typically local, and the digestate – the residual material from the biogas process – is a valuable agricultural fertilizer. During anaerobic digestion of organic residues from sugar manufacture, all valuable minerals remain in the digestate. This material is returned to agriculture, often in cooperation with sugar beet growers, closing the nutrient and mineral cycle. Through local renewable energy production and nutrient recycling, sugar companies reduce their environmental footprint and contribute to a circular, bio-based economy.
Altogether, biomethane represents a key building block for sustainable and economically viable sugar production.

2.1 Energy transition in sugar production in Poland

According to the investor's strategy, the new biogas plant in Poland represents an important step in the sugar company's energy transition, significantly increasing the share of renewable energy in its production processes. Towards achieving production of „green sugar", entirely based on renewable energy, a key milestone was the shift away from coal and coke toward lower-emission natural gas and biogas produced from beet pulp. As part of this transition, a coal-fired boiler was replaced with a gas-fired boiler, and a new gas-fueled lime kiln was installed. However, the existing "small" biogas plant could supply only a portion of the biogas required to meet the factory's energy demand.
In 2023, a contract to design a large-scale biogas plant capable of supplying sufficient energy for sugar production was signed. This new facility is designed to process 300,000 t per year of fresh and ensilaged beet pulp, juice, and other organic by-products from sugar manufacture.
The biogas plant in Poland successfully commenced operations in 2025 and is now producing biogas as planned. Powered by the in-house-produced biogas, the sugar factory now meets its own energy needs. Excess biomethane is fed into the gas grid.

3 Engineering bases and different approaches to biogas plants for the sugar industry

The processing of sugar beet generates residual organic streams such as beet pulp, beet tops and tailings , leaf residues, and molasses that are suitable for biogas production. Utilization of these streams and the closure of the loop are key success factors for each sugar plant.
By-products from sugar beet processing represent valuable feedstocks for anaerobic digestion. Their high organic content and specific biogas production rate make them attractive substrates for biogas plants. Especially beet pulp, which constitutes the bulk of the residual streams, is a valuable material and is readily degradable, producing approximately 140 m^3 (S.T.P.) of biogas per ton of fresh matter. Sugar beet pulp is rich in easily degradable carbohydrates and fiber fractions that support stable microbial activity and typically result in high biogas yields. Beet tops contain a mix of carbohydrates, proteins, and structural fibers, offering good and steady biogas potential. Molasses, with its high sugar concentration, is highly digestible, but must be managed carefully to avoid rapid acidification in the digester. It is also often sold for other purposes.
Designing biogas plants for the sugar industry is a complex task that begins with reliable feedstock data. Basic parameters for determining the suitability of organic streams from the sugar industry for the production of biogas are dry matter and organic dry matter content of the planned feedstock.
For some sugar industry projects, Krieg & Fischer engineers conducted comprehensive, continuous laboratory tests that

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lasted more than six months. Key parameters, such as organic loading rates, were determined and used as the basis for the plant design and layout. With the extensive experience of now 4 large scale biogas plants under operation and 2 in the design/construction phase it is possible to transfer knowledge gained to new projects and reduce the developing time significantly.

To utilize organics from sugar industry in biogas production, seasonal availability of feedstock has to be tackled. The sugar beet campaign typically runs from September to January.

3.1 Traditional approach – constant feeding and biomethane production

While sugar manufacture is seasonal, the standard approach for biogas plants is to maintain a constant consumption of organics. This results in a buffer: fresh input substrates are ensilaged for conservation and year-round use. Feeding is performed by a front-loader using a fully automatic solid feeder, with no additional water supply, directly into the digester tanks. Most of the biomethane plants for the sugar industry are designed and operated in this manner.

The example is one of the first biomethane plants for the sugar industry, built in Germany in 2011. This plant was designed to process 136,000 t/a of feedstock.

Feedstock characteristics are given in Table 1.

Another important question for biogas plant engineering is to define the organic load rate. Earlier projects, such as this plant in Germany, were calculated with moderate load rates of below 5.0 kg volatile solids /(m^3 · d) (Biomethane plant, Germany, 2011).

Table 1: Feedstock mix for design of biogas plant in Germany, 2011

	Annual quantity in t/a	Dry matter input in %	Organic dry matter in %
Sugar beet pulp	120,000	21	96
Beet tops	6,000	22	94
Vinasse	10,000	64	71

From the outset of the German plant operation, real-world performance exceeded laboratory test results. Production is above planned 22.2 mn m^3 (S.T.P.) of biogas per annum. After biogas upgrading, the entire biomethane production is fed into the gas grid. Over the years, performance has even improved due to more skilled staff and the addition of more specific trace-element supplements.

3.2 Flexible operation aligned with beet campaigns

In the latest project for a sugar producer in Poland, the concept differs: During the beet campaign, feedstock input is maximized to match the sugar plant's energy demand, whereas outside the campaign, the feeding rate is reduced to 5–10%.

During the beet campaign, which lasts approximately 130 days, the biogas plant is at maximum production, processing fresh sugar beet pulp, delivered hot at about 55° C. Outside the campaign, biogas is produced from ensiled sugar beet pulp, with a large number of different processes between; such as for the speciality sugar campaign period, the thick juice campaign period and the high/down periods – all of which introduce variability to the process. The total feedstock quantity for biogas production in the Polish factory is 300,000 t/a.

Since this plant operates on a seasonal basis, the complexity of its engineering is significantly increased. Energy demand profiles of the sugar factory, derived from a detailed engineering study, served as the basis for plant design and capacity sizing. Figure 1 shows the estimated energy needs of sugar production from an engineering study for a biomethane plant. Biogas production is aligned with the sugar plant's needs.

In the annual operating plan, the year begins at 100% capacity utilization. With the end of the sugar campaign in January, feeding is reduced to about 50% during speciality sugar campaign. Later feeding is reduced to 5–10% to keep the system alive till March, when the thick juice campaign starts. Within 3 weeks of start-up, feeding is increased again to approximately 60% of maximum capacity. After about 50 days, feeding is reduced again till the start of the next sugar beet cam-

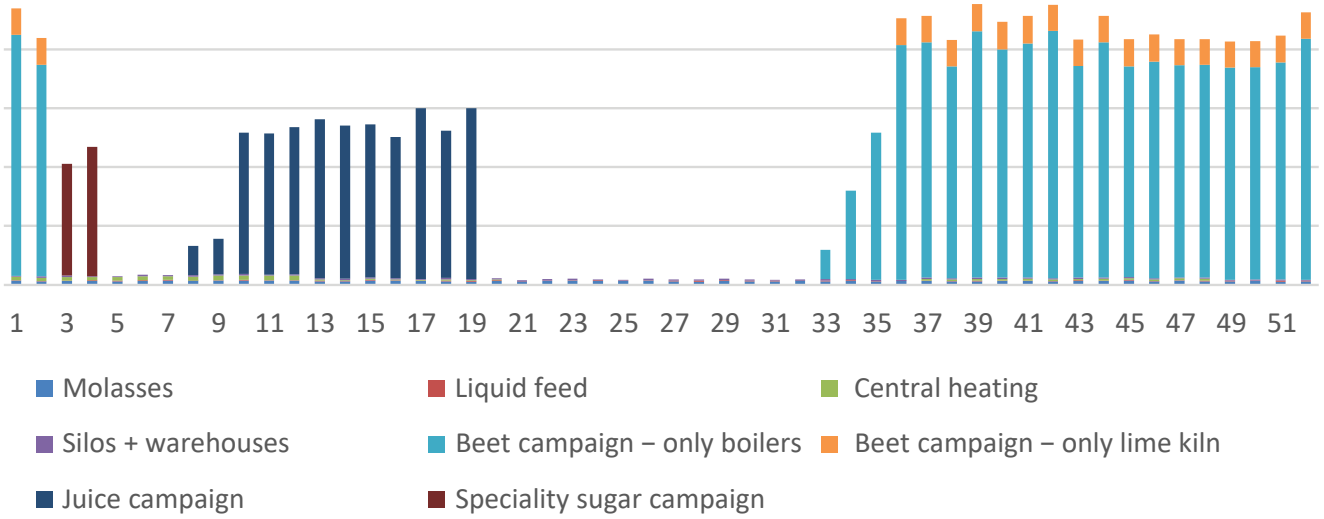

Fig. 1: Energy needs of sugar plant as a base for engineering, illustration of weekly consumption (Source: sugar factory, Poland)

paign. One month before the campaign begins, feeding is increased to achieve full production during sugar beet processing, when energy is required.

During the sugar beet campaign, the plant's digesters in Poland are fed with fresh, hot sugar beet pulp directly from the factory. Another part of the fresh sugar beet pulp is ensilaged in the silage area for year-round use. The switch from silage to fresh sugar beet pulp is made at the beginning of the sugar beet campaign. Silage must be replaced step by step with fresh sugar beet pulp to allow the bacteria to adapt as the load increases significantly.

The plant commenced operation in March 2025. The operators had no issues during normal start-up/operation by learning how the equipment should be operated. It is running, and the operators reached the target biogas production in stable conditions.

For this project, the maximum organic load rate is higher than in most existing plants: 8 kg volatile solids/(m^3 · d). Such a high organic load rate requires specific technical and biological measures to maintain strong biological activity and prevent foam formation. However, in combination with proper design, continuous consulting by Krieg & Fischer, and a strong operational team, the load rate has been achieved quickly and without major issues.

4 Technical overview and integration into existing infrastructure

The optimal design of a biogas plant requires engineers to address a wide range of technical questions. One of the key design decisions concerns the anaerobic digestion system itself, starting with the selection of digester technology.

In large-scale biomethane plants, upright digesters with a solid roof and a top-mounted mixer can be considered the most reliable and efficient system. With biogas upgrading, the only and primary "natural" heat source for digester tanks are the compressors that supply biomethane into the natural gas grid. Heat is highly valuable and must be used very carefully. To minimize heat loss, digester tanks are fully insulated. In flat digester tanks, most annual heat loss results from heat transfer through the open tank top, which is only covered by a gas membrane. High-digester tanks with top-mounted mixers and external heat exchangers have proven to be the best solution for large-scale biomethane plants in the sugar industry.

The newly-built biogas plant for the Polish sugar factory is a comprehensive, large-scale system designed for seasonal flexibility and high operational efficiency. The facility includes: 4 digesters (high steel tanks with a gross volume of 10,400 m^3 each); 2 secondary digesters with gas-holding roofs; external gas storage; and a biogas pretreatment unit that encompasses biological desulphurization, compression, biogas cooling, and an active carbon filter.

To minimize heating and cooling requirements, operation is thermophilic. During the beet campaign, beet pulp is transported directly from the sugar factory to the biogas plant via belt conveyors and is fed into the digester almost immediately. Its temperature is 50–60 °C. Mesophilic operation would require an active cooling of pulp and digesters. The operating temperature may fluctuate within certain limits to optimize heating and cooling demand.

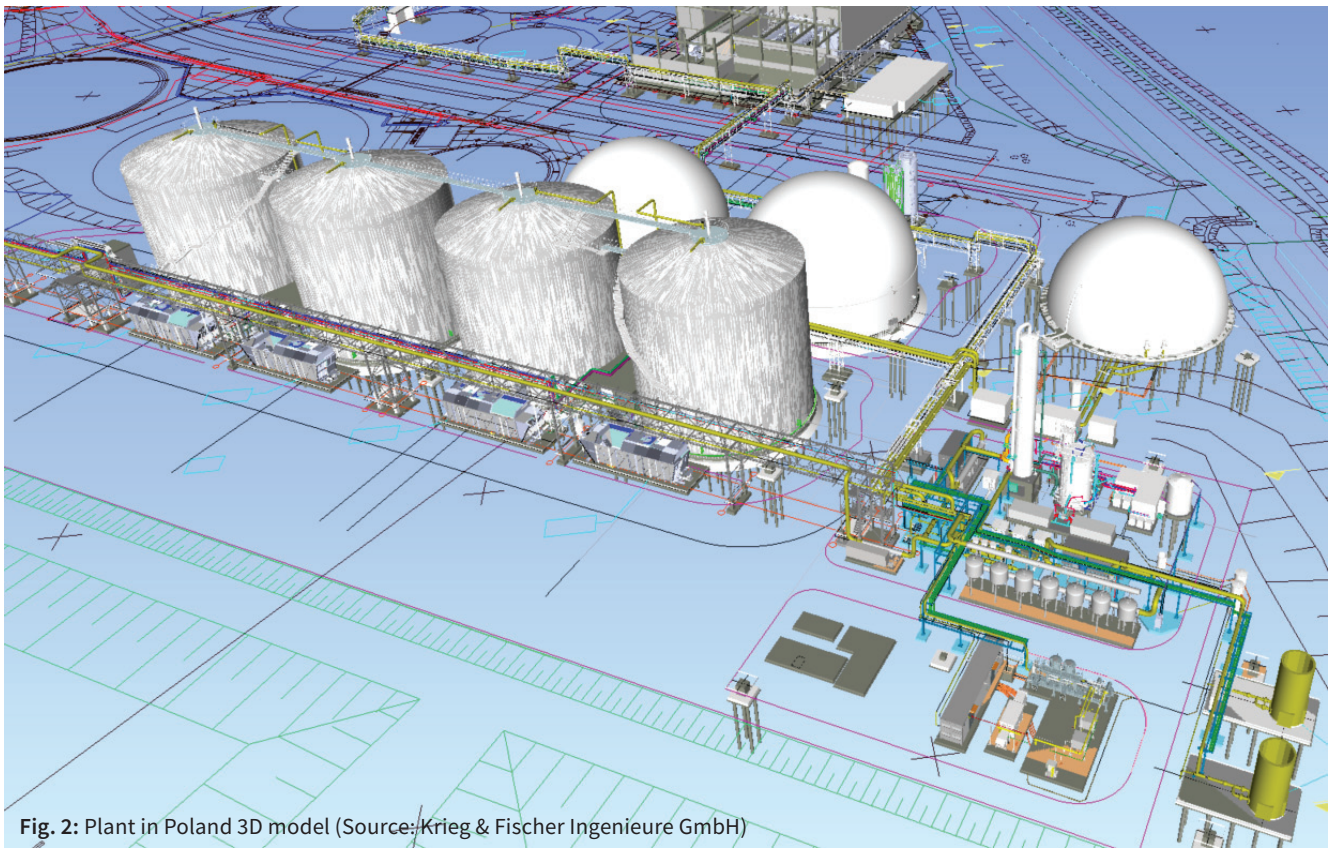

Fig. 2: Plant in Poland 3D model (Source: Krieg & Fischer Ingenieure GmbH)

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The biogas utilization system comprises 2 cogeneration units, a biogas upgrading system, 2 boilers (steam and hot water), and a biogas-fueled lime kiln.
As the final step, there is also a digestate treatment plant for both digestate flows, from existing and new plants, ensuring environmentally compliant discharge. The digestate from biogas production is treated to produce purified water (for discharge) and solid and liquid fertilizer concentrates. The digestate treatment plant comprises multiple stages: chamber filter presses with oxidative pretreatment for primary liquid-solid separation, followed by ultrafiltration to remove fine particles down to 50 µm. A reverse osmosis stage removes dissolved salts and produces drinking water. The concentrate is a valuable fertilizer.

4.1 Gas production and utilization

Biogas production is planned at more than 8500 m^3/h (S.T.P.) during the sugar beet campaign and at about 430 m^3/h (S.T.P.) outside the campaign. Gas utilization is tailored to fit seasonal energy demand, balancing on-site consumption and biomethane injection into the national gas grid.
During the campaign, biogas will primarily be utilized for heat and power production. Additionally, 800 m^3/h (S.T.P.) is directed to the upgrading unit, whereas flow to Combined heat and power plants (CHPs) of 800 kW_{el} and 1200 kW_{el} will use up to 630 m^3/h (S.T.P.). Outside the campaign, biomethane is supplied to the natural gas grid. The new plant is connected to the existing biogas infrastructure, particularly for biogas processing and digestate treatment.

5 Challenges in the energy transition of sugar production to biogas

The biogas plant for the Polish sugar factory highlighted several engineering and operational challenges, providing valuable insights for the investor and engineering companies.
Solutions for sugar industry biogas plants have traditionally been designed for maximum availability and (stable) gas production, with flexibility in gas utilization. However, the latest project in Poland was a challenging task from different aspects.
This plant is designed for flexible, seasonal operation of the complete plant. Feeding is not constant, but with high variations between the sugar campaign, the thick juice campaign, and the off campaign. This fluctuating load, including the temperature management, was a big challenge for engineers. For the operators, maintaining microbial stability under changing feedstock conditions requires careful planning and management.
Given the biogas plant's production and the factory's heat and electricity demand, a flexible and efficient system was required, and the plant had to be integrated into existing infrastructure and operations. This integration provides that most biogas is used on-site for steam generation, while surplus gas is upgraded to biomethane for grid injection. Outside the campaign, the biomethane supply ensures a continuous economic income. The design of the gas system for such a large plant was complex, as it encompasses gas distribution and pressure management under highly variable loads and multiple gas users. The engineering team had to take into account the envelope of all possible different cases between the producers (4 digesters and old biogas plant) and the consumers (lime kiln, hot water boiler, steam boiler, 2 cogeneration units, flare 1, flare 2, gas upgrading system) with the biogas pretreatment (external biological desulphurization, biogas coolers, final fine desulphurization) and the gas storage system.
One of the major challenges was the complex treatment of digestate, in accordance with stringent requirements for environmentally compliant discharge. This segment is sometimes not emphasized enough. Digestate treatment must be considered an integral part of the biogas/biomethane plant, as stringent environmental regulations require proper operation; otherwise, gas production may be halted. It can also entail high investment costs and be energy-intensive. Technology-wise, digestate treatment was one of the most complicated issues. It is a general challenge in biogas plant design: the properties of the digestate are typically unknown before commissioning, particularly for plants using uncommon substrates and when ambitious treatment targets are required. In this case, the task for engineers and subcontractors regarding output streams was to achieve clean water and very concentrated fertilizer products.
Finally, the project timeline was a big challenge. The entire project, from initial concept to commissioning, was delivered in just two years. The tough timeline put a lot of pressure and risk on the project team, but with good organization and high effort from all parties, it could be realized.

Fig. 3: Plant in Poland in operation

References

Fischer, T. Latinovic, S. (2021): A real gas – How biogas is contributing to the success of sugar producers, *Sugar Producer August/ September 2021*, 18–19
Nordzucker (2025): Focus Future, *Annual Report 2024/2025*