Best Practices on flexible bioenergy

Unlocking Biogas Flexibility for Sustainable Security

Bevtoft, Southern Jutland, Denmark

IEA Bioenergy Task 44
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Introduction

Biogas is a versatile energy carrier produced from organic residual materials that can make a significant contribution to sustainable energy supply. This factsheet provides a generally understandable overview of the fundamentals of biogas production, the advantages of its flexible application, and the role of biogas in the context of the energy transition with a special focus on **flexibility**. The first part explains key technical and environmental aspects of biogas. The second part presents a concrete project example, chosen from IEA Bioenergy Task 37 database/collection, that demonstrates how flexible use of biogas is implemented in practice and the added value it brings to the energy system.

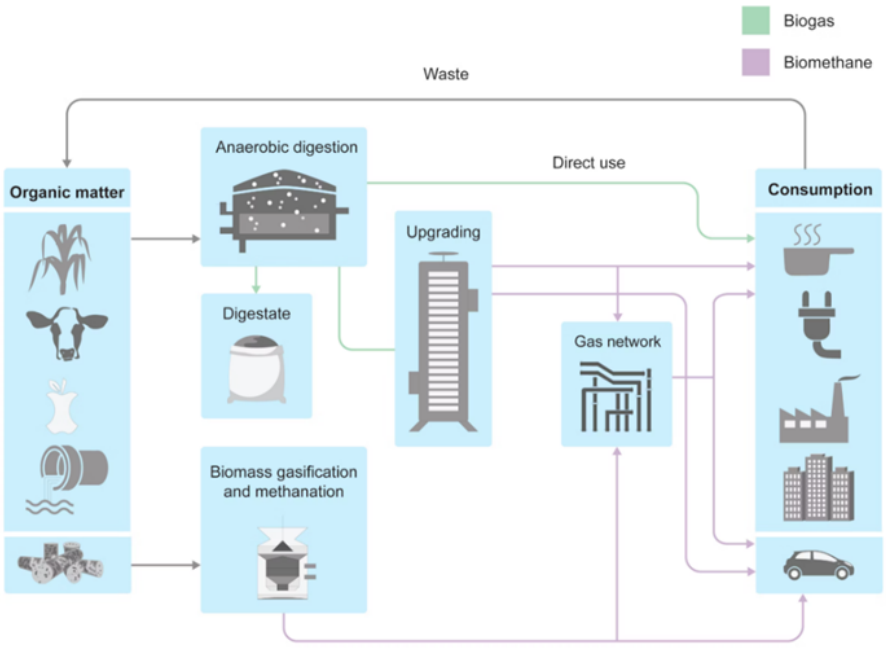


Figure 1: Biogas and biomethane production pathways, Outlook for biogas and biomethane - Prospects for organic growth, World Energy Outlook Special Report, IEA March 2020.

General introduction in technical and environmental aspects of flexible biogas processes

Feedstock flexibility

Biogas plants can process a wide range of organic materials, such as agricultural residues, energy crops, manure, food waste, and industrial organic waste. This feedstock flexibility reduces dependency on single resources and allows operators to respond to seasonal or regional feedstock availability. Multi-feedstock plants are especially effective, as they can switch between different inputs depending on price and supply.

Smart fact: Co-digestion of maize, grass silage, manure, and waste can reduce global warming potential by up to 48 % in flexible feeding scenarios pubmed.ncbi.nlm.nih.gov.

Flexibility through bioenergy carriers

Biogas can be converted into various forms of usable energy: raw biogas for heat production, upgraded biomethane for injection into the natural gas grid, electricity through power generation in a combined heat and power plant, or as a fuel for vehicles. This carrier flexibility enables targeted use across electricity, heat, and transport sectors. Furthermore, storing biomethane allows for spatial and temporal decoupling of production and consumption, adding temporal flexibility.

Smart fact: Did you know that a single biogas plant can provide multiple energy solutions? In winter, raw biogas heats homes and farm buildings. In summer, upgraded biomethane is injected into the natural gas grid to power households and industries. When electricity demand peaks, biogas can fuel a combined heat and power plant to generate electricity and heat (check facts at the example Canadian Lethbridge biogas/cogeneration plant). Biomethane can also be used as a fuel for vehicles, such as tractors or at filling stations!

Operational flexibility

Advanced biogas plants can adjust their electricity and heat output based on real-time demand, contributing to grid stability and supporting intermittent renewables like wind and solar. This requires smart control systems and sufficient gas storage capacity to balance the difference between constant gas production and fluctuating energy output.

Smart fact: For instance, German plants employing model-predictive control align biogas production with grid demand, enabling intraday flexibility of up to 50 % and reducing storage needs by 65 % mdpi.com/2076-2607/10/4/804. Flexible operation via additional combined heat and power plant and scheduled dispatch supports grid services and market participation.

Product flexibility

In addition to energy, biogas plants can produce a variety of value-added products such as biomethane, purified CO_2 for industrial use, and organic fertilizer from digestate. Increasingly, they are also being integrated into biorefineries and circular economy models, producing platform chemicals, bioplastics, or proteins from by-products.

Smart fact: Facilities such as Germany's BioEnergie Park Güstrow produce bio-LNG for heavy transport and recover CO_2 for industry, demonstrating carrier versatility envitec-biogas.co.uk/references/guestrow#.

Box 1: Advantages of flexible biogas systems

The key advantage of **flexible biogas systems** is that they provide **reliable and resource-efficient energy, making them a valuable asset in a volatile energy market.** Compared to mono-feedstock, baseload-oriented, and single-product bioenergy systems, flexible biogas plants are more robust, adaptive, and future-proof.

Resilience through diversification

Flexibility enables biogas systems to buffer variability, uncertainty, and disruptive events. Feedstock diversification reduces dependence on individual substrates and helps stabilize biological processes, as variations in feedstock quality or availability can be balanced through multi-feedstock plants. Supply shocks or seasonal shortages are therefore absorbed through a diversified feedstock portfolio rather than addressed through costly redundancies, such as multiple single-feedstock plants or additional storage.

Similarly, **flexible utilization of biogas and biomethane** mitigates demand-side risks. For example, even though residential gas heating is being phased out in parts of Europe, upgrading biogas to biomethane de-risks biogas plants by opening access to a wide range of alternative applications, including industrial high-temperature heat, transport, and dispatchable electricity generation and district heating during cold, dark, and wind-poor periods.

System integration and sector coupling
Flexible biogas systems act as **connectors between sectors**. By converting organic residues into a storable and transportable energy carrier, they enable balancing across **time, space, and energy sectors**. Biomethane can be stored seasonally, transported via existing gas infrastructure, and converted into electricity or heat when needed, directly supporting power systems with high shares of wind and solar energy.

Further integration options, such as bio methanation concepts with renewable hydrogen, allow biogas systems to valorize surplus renewable electricity during periods of excess generation. In this way, flexibility transforms variability in one part of the energy system into a stabilizing resource elsewhere.

Resource-efficient reliability instead of redundancy
Beyond energy security, flexible biogas systems contribute to **food security, environmental protection, and circular resource use**. Many plants are designed primarily to support agriculture and the food processing industry by organic waste, improving water quality, and closing nutrient cycles through digestate recycling.

In contrast to traditional security strategies based on baseload operation, back-up capacity, and crisis response measures, flexible biogas systems deliver **reliability through uncertainty-aware operation**. By actively balancing resources across feedstocks, products, time horizons, and end-use options, flexibility allows periods of abundance to be transformed into long-term reliability — simultaneously improving efficiency and resilience.

Strategic value for future energy systems
When well-coordinated, flexible biogas systems strengthen energy systems by:

- reducing exposure to market, policy, and technology shifts,
- increasing adaptability to changing demand patterns,
- and supporting low-carbon energy and food systems.

Flexibility therefore elevates biogas from a single-purpose renewable energy option to a **strategic system asset** capable of addressing multiple societal objectives at once.

Coordination needs for flexible biogas

To harness the many advantages of flexible biogas processes, continuous and smart coordination of the following aspects must be ensured:

Coordinating high technical and logistical complexity
Flexible operation (e.g. demand-oriented electricity generation) requires larger gas storage systems, fast-responsive engines, and intelligent control systems. Frequent start-stop cycles in flexible operation led to more wear and tear, resulting in higher maintenance requirements and reduced component lifespan.

Risking higher investment and operating costs
Initial investments for flexibility (e.g. storage tanks, gas upgrading, control systems) can be significant. Operating costs increase due to more complex systems, additional personnel, and ongoing management of varying inputs and outputs.

Coordinating market volatility
The profitability of flexible biogas use often depends on external market factors such as natural gas and electricity prices, CO_2 credits, and subsidies, which are subject to volatilities. Flexible coordination is required, continuously updating and matching operational and strategic plans.

Coordinating feedstock flexibility
Switching between different substrates needs to consider:

- Unstable biogas production due to varying feedstock quality,
- Biological issues in the digester (e.g. imbalanced C/N ratios or inhibitory compounds),
- Increased logistics needs for storage, transport, and processing of diverse feedstocks.

Coordinating sustainability concerns
High product flexibility (e.g. producing fuels, chemicals, or biomethane) can increase raw material demand. Use of certain feedstocks (e.g. energy crops) may lead to land-use conflicts, monocultures, or environmental degradation, raising sustainability concerns.

Regulatory and permitting challenges
Flexible plants that produce multiple outputs and operate in various modes often face more complex regulatory requirements. Changes in operational strategies may require new permits or additional environmental assessments, causing delays and added costs.

Key Takeaways

The multiple flexibility options of biogas make it a strategic asset in the renewable energy mix. Leveraging feedstock, carrier, operational, and product flexibility enables biogas systems to be more efficient, resilient, and sustainable. Future development should focus on integrating these flexibilities to fully exploit the potential of biogas in a dynamic energy landscape.

Flexible biogas use holds great potential but comes with technical, economic, and administrative challenges. Without appropriate support mechanisms (e.g. market incentives, grid access, favorable regulation), it may become unprofitable or overly complex. Careful planning, technical expertise, and a stable policy environment are key to realizing the benefits of biogas flexibility.

Untapped opportunities lie in enabling and harnessing the flexibilization potentials of existing and next-generation biogas plants. IEA Bioenergy Task 44 focuses on the convergence of strategic planning and operational control to align plant level economic, ecological, and social sustainability with system wide resilience, reliability, and security goals. This twofold objective is the unique selling point of well-integrated, and flexibly operated bioenergy activities.

SØNDERJYSK BIOGAS BEVTOFT - Hi-tech Danish biogas installation a key player in rural development

An IEA Bioenergy **Task 37 Case Story** presents an anaerobic digestion technology or concept that is innovative, is in commercial operation and provides an exemplar of the biogas industry. For this factsheet, we choose an example for flexibility in Denmark, Hjartbro, which will be presented below.

Link:

https://task37.ieabioenergy.com/wp-content/uploads/sites/32/2022/03/Danish_Case_Story_web_new.pdf

Jørgensen, Jesper; Berndt, Marina and Dalby, Michael (2018): SØNDERJYSK BIOGAS BEVTOFT- Hi-tech Danish biogas installation a key player in rural development. Case story Denmark. IEA Bioenergy Task 37. Available at: https://task37.ieabioenergy.com/wp-content/uploads/sites/32/2022/03/Danish_Case_Story_web_new.pdf

1. Project description

Sønderjysk Biogas Bevtoft processes around 600,000 tons of manure, straw, sugar beets, and maize annually in large thermophilic digesters, upgrading the biogas to high-purity biomethane (>99%) that is injected into the Danish gas grid. The main products are biomethane and nutrient-rich digestate used as fertilizer. Flexibility comes from the ability to use multiple feedstocks depending on season and availability, and to deliver the biomethane flexibly into different sectors (heating, transport, industry). This flexibility helps the energy system by ensuring a stable renewable gas supply, balancing variable biomass inputs, and supporting Denmark's need for dispatchable renewable energy alongside intermittent wind and solar.

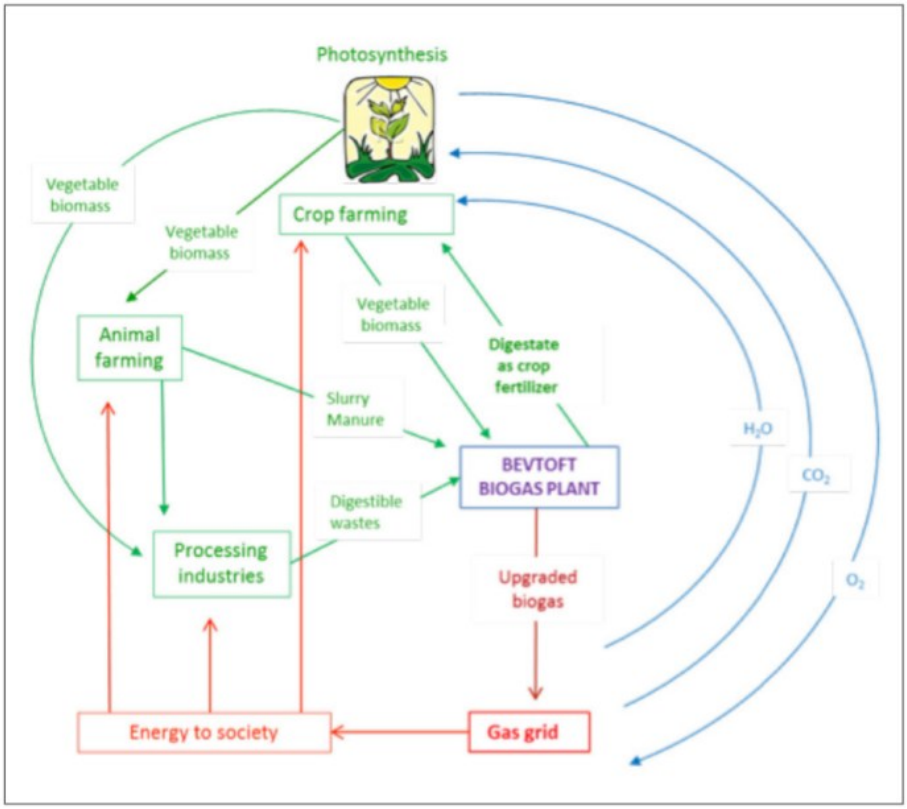


Figure 2: The closed loop of biogas – a simplified biomass and biogas flow diagram of Bevtoft Biogas Plant; figure 3 from Task 37 case story: https://task37.ieabioenergy.com/wp-content/uploads/sites/32/2022/03/Danish_Case_Story_web_new.pdf.



Figure 3: Overview of the Sønderjysk Biogas Bevtoft plant.
Source: https://www.soenderjyskbiogas.dk/?page_id=52

Base information	
Link for more information	IEA Bioenergy Task 37 – Sønderjysk Biogas Bevtoft case study https://www.soenderjyskbiogas.dk/
Contact person, email	Jesper Jørgensen; Plant Operator, Bevtoft Biogas Plant, +45 23 21 41 95, jj@sbgas.dk; Marina Berndt, Managing Director, Sønderjysk Biogas, +45 5126 9012, mb@sbgas.dk; Michael Dalby, Managing Director, E.ON, +45 3038 6137, Michael.Dalby@eon.dk
Location	Bevtoft, Southern Jutland, Denmark
Owner/Operator	Joint venture: E.ON + Sønderjysk Biogas Invest A/S (owned by local farmers)
Technology supplier	N-ERGY / N-Bio (engineering & plant construction); Wärtsilä (biogas upgrading); Jakobsen & Blindkilde A / S, Farmatic Anlagenbau GmbH, Purac Puregas GmbH
Facility planned since/Start of the project	Planning began ~2014; start of operation 2016
Construction year	2014–2016
Status	Commercial full-scale facility
Feedstock	~600,000 tons/year of manure, straw, sugar beets, maize (multi-feedstock co-digestion)
Products	Biomethane (>99% purity) injected into grid; digestate used as fertilizer; Biomethane output: ~21 million Nm^3/year (≈ 200 GWh/year energy content)
Type of flexibility provided	Feedstock flexibility; modular digester capacity; biomethane upgrading (flexible output use in gas grid, heating, transport)

Flexibility characteristics	Ability to use multiple feedstocks depending on season and availability Output can be directed to gas grid (heating, industry, transport) Modular design allows scaling Digestate recirculated as fertilizer; contributes to nutrient cycling
Investment cost of the plant	~€33 million Euro (2016)

Flexibility aspects of the Sønderjysk Biogas Bevtoft plant

The plant provides several types of flexibility. It can process a wide range of feedstocks, enabling substrate flexibility. In addition, the produced biomethane can be used for different purposes such as heating, electricity generation, or transport, which ensures output flexibility. The modular design of the plant also allows for capacity expansions, contributing to operational flexibility.

These flexibility characteristics allow the plant to adjust feedstock use depending on seasonal availability of agricultural residues. Furthermore, the energy output is not restricted to local consumption, as the biomethane is injected into the gas grid and can be used nationwide. The infrastructure is designed for gradual scaling, which helps to avoid technological lock-in.

Table 1: Flexibility aspects of the Sønderjysk Biogas Bevtoft plant.

Flexibility in renewable resource types	**Details (number, capacity)**
Biogenic residues from food provisioning system (agriculture, livestock, wastewater)	Animal slurries 425,000 tons Animal bedding /deep litter 10,000 tons Straw 50,000 tons Organic wastes 55,000 tons
Flexibility in energy inputs and outputs	**Details (capacity)**
Gaseous bioenergy carriers output	Producing of about 30 million cubic meters of methane (equivalent to energy for 21,500 households or biofuel for 14,000 passenger cars) – storable and tradeable in existing gas infrastructure
Flexibility in providing societally relevant services	**Details**
Residential heating and cooling	Upgrading with Amino technology and selling the biomethane to the gas network, flexible use either for electricity production for electrified heating and cooling, or gas use in district heating plants or in households
Integration across sites, networks and markets	**Details**
Cross-sector or community integration (industrial symbiosis, energy community)	Improvement of the economy of the farm through higher crop yields Monetary savings for farmers in purchase of mineral fertilizers Creation of 10 permanent jobs

Feed-in to national energy grids or markets	Improvement in security of energy supply
On site, integrated system	Reduction in the environmental impact of agriculture
Non-energy products	**Details**
Digestate-based fertilizer	No further information provided
Time scale of temporal flexibility	**Details**
Months	Long-term storage of biomethane in existing gas storage infrastructure and strategic gas reserves
Seasons	Biomethane can be stored over longer periods, providing seasonal energy security
Other criteria	**Details**
Other	Production of decarbonized energy, resulting in a CO2 reduction of 51,000t each year
Other	Reduces odor, nitrate leaching and nitrous oxide when spreading slurry

2. Technical and commercial details

2.1. Execution and operation of the plant

The Sønderjysk Biogas plant in Bevtoft began operation in 2016 and is operated as a joint venture between E.ON and a farmer-owned company (Sønderjysk Biogas Invest A/S). The plant processes up to 600,000 tons of biomass annually, primarily consisting of animal slurry, along with straw and organic industrial waste.

The anaerobic digestion process is carried out in two stages: a thermophilic phase at 52 °C followed by a mesophilic phase at 35 °C. All incoming materials are weighed to ensure full traceability of inputs and outputs, allowing monitoring of both efficiency and economic performance.

The produced biogas is upgraded to biomethane by removing CO_2, hydrogen sulphide, and water using an amine scrubber process. The upgraded gas reaches a methane content of over 99% and is injected directly into the natural gas grid without the need for propane enrichment.

The resulting digestate is returned to farmers as a biofertilizer, contributing to nutrient recycling and forming part of a circular economy system.

2.2. Economic description

The total investment cost of the plant was approximately €33 million. This includes the construction of the facility as well as the installation of advanced biogas upgrading technology.

Feedstock is sourced locally, mainly from farmers supplying slurry and agricultural residues, as well as organic waste from industry. The economic system is closely linked to these local supply chains.

Cost efficiency is achieved through several technical features: a methane recovery rate above 99.9%, the elimination of propane enrichment, and no additional energy demand for off-gas treatment.

Economic value is generated through biomethane sales to the gas grid as well as indirect savings from replacing mineral fertilizers with digestate in agriculture.

2.3. Business model and economic viability

The plant operates within a cooperative and partnership-based business model, involving both a large energy company and local farmers. Farmers supply feedstock and benefit from receiving digestate as fertilizer.

Economic viability is supported by direct access to the natural gas grid, ensuring a stable market for biomethane. Strong local participation also secures feedstock supply and operational continuity.

In addition, the project benefits from supportive political and societal frameworks promoting renewable energy and agricultural decarbonization. It aligns with broader goals of climate neutrality, rural development, and sustainable and resilient agriculture.

2.4. Differences from previous or existing plants

Compared to conventional biogas plants, the Bevtoft facility differs in several key aspects.

It operates at a large industrial scale, processing up to 600,000 tons of biomass annually. It also uses advanced amine-based upgrading technology, achieving very high methane purity and efficiency.

Unlike many traditional systems, it does not require propane enrichment, which simplifies operation and reduces costs. Its ability to handle multiple feedstocks increases operational flexibility and resilience.

Another key difference is its strong integration with local agriculture, where farmers are both suppliers and co-owners. This strengthens local acceptance and long-term stability.

Overall, the plant represents a high-tech example of manure-based biogas production combining energy generation with circular economy principles.

3. Market Opportunities

3.1. Need for flexibility and system benefits

The injection of biomethane into the natural gas grid enables energy use across regions and sectors, significantly increasing system flexibility. It allows renewable gas to be transported and stored using existing infrastructure, improving energy security and diversification.

The ability to process multiple feedstocks ensures stable operation even when biomass availability fluctuates seasonally, strengthening system reliability.

3.2. Drivers and enabling factors

The project was driven by political and societal incentives to better utilize agricultural biomass, reduce emissions, and support the transition to a fossil-free energy system. Strong local participation, particularly from farmers, was a key factor in securing feedstock supply and ensuring project acceptance.

3.3. Environmental benefits

The plant reduces CO_2 emissions by approximately 51,000 tons per year. It lowers the environmental impact of agriculture by treating slurry and organic waste, reduces odors, and decreases nitrate and nitrous oxide emissions. The use of digestate as biofertilizer improves nutrient recycling and reduces the need for mineral fertilizers. In addition, the project supports rural development and job creation.

3.4. Challenges and barriers

The implementation of such plants is associated with several barriers. High upfront capital investment represents a significant challenge, as substantial financial resources are required for construction and technology. In addition, economic viability depends on stable policy frameworks and continued support for biomethane, making the project sensitive to regulatory changes. Logistical challenges also arise from the need to collect, handle, and transport large quantities of agricultural residues efficiently. Additionally, key factors for implementation include the availability of biomass, strong stakeholder cooperation, and public acceptance. Continuous dialogue with local communities is highlighted as important for project success.

4. Lessons to Industry

4.1. Lessons learned

The case demonstrates that **multi-feedstock digestion significantly reduces operational risks compared to monoculture feedstock systems**, as it allows flexible use of manure, straw, and organic residues and improves supply security. This flexibility strengthens plant reliability and reduces vulnerability to seasonal or market fluctuations.

A further key insight is that combining **utility-scale expertise with farmer ownership creates strong local anchoring**, which improves both operational reliability and long-term feedstock availability. The cooperative structure enhances trust and ensures active participation from local stakeholders.

The project also shows that **biomethane upgrading enables integration into multiple energy markets**, since the gas can be injected into the national grid and used for heating, electricity, or transport. This market flexibility contributes to a more resilient and future-proof business model.

In addition, **visual and environmental integration into the landscape is essential for public acceptance**, as local support and continuous dialogue with communities play an important role in successful implementation and operation.

4.2. Key Challenges

Long-term investment security depends on **stable and predictable policy frameworks**, which are necessary to support continued expansion of biomethane infrastructure. Without this stability, investment willingness may be reduced.

Operational efficiency could be improved by **optimizing logistics systems**, particularly for the transport and handling of manure and other bulk feedstocks, which represent a significant cost and coordination factor.

Finally, **simplifying permitting and approval procedures** would help accelerate the replication of similar biogas projects, reducing administrative barriers and enabling faster deployment of renewable gas solutions.

5. Policy

5.1. Embedding in regional energy and climate strategies

The project is embedded in broader Danish and regional objectives to reduce carbon emissions and support the transition towards a fossil-free energy system. It was facilitated by capital investment grants (*anlægsstøtte*) provided under the Danish Biogas Support Scheme (*biogaspulje*). This scheme was/is a key component of the strategic framework established by the **Danish Energy Agreement of 2012**. It contributes directly to climate goals by producing renewable biomethane that replaces fossil natural gas in the national grid. In addition, it supports agricultural policy aims by improving the treatment and value of manure and organic residues, turning them into renewable energy and nutrient-rich fertilizer. The project also aligns with regional development goals by strengthening rural economies and creating local value through energy production and job creation.

5.2. Local community involvement

The local community is strongly involved in the project. The plant is operated as a joint venture that includes a cooperative owned by local farmers, meaning that farmers are not only suppliers of biomass but also co-owners of the facility. Local stakeholders were consulted throughout the decision-making and development process, which helped build acceptance from the beginning.

6. Outlook and Further Development

6.1. Next steps and planned developments

There are no specific planned expansions described for the Bevtoft plant. However, the plant is already designed for **scalable and modular operation**, meaning that future capacity increases could be implemented through its flexible infrastructure. The existing upgrading and grid connection setup also allows continued efficient integration of additional biomass inputs and stable biomethane production over time.

6.2. Contribution to future decarbonization and system integration

The concept contributes to long-term decarbonization by producing **high-purity biomethane (>99%)** that directly replaces fossil natural gas in the national grid. This enables large-scale substitution of fossil energy without requiring changes in end-user infrastructure.

System integration is strengthened through the ability to inject biomethane into the grid, allowing renewable energy to be distributed flexibly across sectors such as heating, transport, and electricity. The use of multiple feedstocks also supports resource efficiency by converting agricultural residues into renewable energy and circular fertilizer products.

Overall, the concept supports a **circular bioeconomy**, combining waste valorization, renewable energy production, and nutrient recycling, which enhances both decarbonization and systemic flexibility in the energy system.

In summary, this combination makes Sønderjysk Biogas Bevtoft a strong example:

- Scalability & robust infrastructure → adapts to biomass availability, biomethane demand, environmental requirements.
- Diverse substrates and outputs → increases resilience to price and availability changes.
- Local participation & acceptance → reduces social risks, organizational barriers, political resistance.
- Integration into existing energy systems (gas grid, heating, transport) → ensures multi-functional usefulness.
- Technical innovation & continuous improvement → upgrading, environmental technologies, etc.

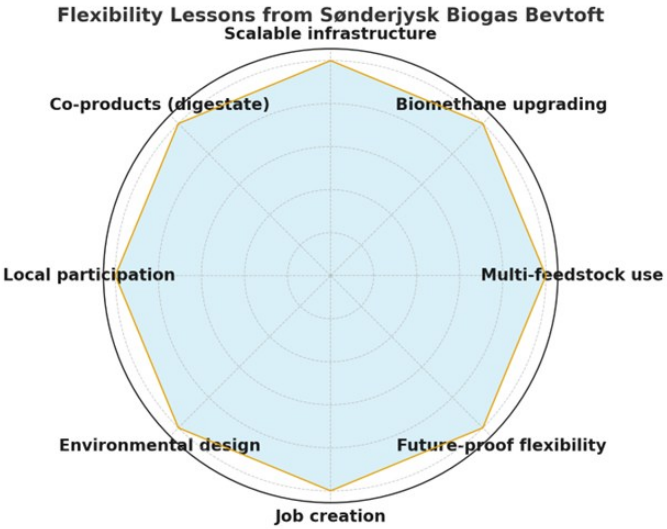


Figure 4: Key flexibility aspects from Sønderjysk Biogas Bevtoft project, created with OpenAI, 2026





Figure 5 and 6: Location and view of the Sønderjysk Biogas Bevtoft plant.
Source: https://www.soenderjyskbiogas.dk/?page_id=52

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