Journal of Marine Technology and Environment
DOI:10.53464/JMTE.02.2025.11
ISSN (Print): 1844-6116
ISSN (Online): 2501-8795
https://www. jmte.eu

GASIFICATION OF AGRICULTURAL RESIDUAL BIOMASS AND ORGANIC WASTE FROM THE FOOD INDUSTRY

Lucian-Georgel UNGUREANU[1], Ana-Bianca MITITELU[1]*, Sergiu CILIUȚĂ[1], Daniela-Florentina ROȘCA[1], Lucian-Samuel BOIAN[1]& Pavel ATANASOAE[1]

[1] Faculty of Electrical Engineering and Computer Science, Stefan cel Mare University of Suceava, 13 Universitatii Street, Romania, corresponding e-mail address: ana.mititelu@student.usv.ro

Abstract : Biogas is an increasingly important renewable energy resource in a world facing environmental challenges and the urgent need for sustainable solutions. Produced through the anaerobic decomposition of organic materials, biogas offers an efficient means of valorising organic waste. The production process yields a gas mixture, primarily methane and carbon dioxide, that can be converted into electricity, heat, or fuel, thereby contributing to the reduction of greenhouse gas emissions. Moreover, it supports a sustainable resource cycle, making this technology a highly promising solution for the future of green energy. This study presents a comparative analysis of the operational performance of the Moara-Suceava biogas plant when using agricultural residual biomass (corn and animal waste) versus organic waste from the food industry. The results indicate that, although larger quantities of raw material are required to produce the same volumetric amount of biogas from food industry waste, the latter yields higher lower heating values (5.81–6.20 kWh/Nm³) compared to agricultural residual biomass (4.50–4.91 kWh/Nm³).
Key words : Biogas, agricultural residual biomass, gasification, organic waste, cogeneration.

1. INTRODUCTION

Global efforts to decarbonize the energy sector have accelerated interest in renewable technologies. Biomass, as an abundant organic resource, can be converted into clean gas through thermochemical processes. Modern bioenergy contributes significantly to renewable energy supplies, and projections by the International Energy Agency (IEA) and the International Renewable Energy Agency (IRENA) indicate that biomass could play an even greater role by 2030 [1,2]. Gasification (a high-temperature process that converts biomass into a combustible gas mixture known as syngas) has emerged as one of the most efficient pathways for utilizing organic materials. Syngas can be used for power generation, district heating, or as a feedstock for synthetic fuels and chemicals [3]. Biomass gasification offers a promising route to generate renewable gas fuels while reducing greenhouse gas emissions and dependence on fossil fuels.

The biomass plant in Moara-Suceava taken into consideration for the case study, uses a fluidized-bed gasifier, chosen for its flexibility in processing various types of biomass and its ability to produce consistently high-quality syngas. Initially, the plant operated using silage corn and organic residues, but to capitalize on local agricultural by-products, it later integrated animal waste, such as zoogenic biomass. This transition introduced operational challenges, including increased nitrogen and sulfur content in the feedstock, requiring upgrades to the cleaning systems. However, thanks to its adaptable design, the fluidized-bed gasifier maintained operational efficiency, demonstrating the viability of this technology in different biomass utilization scenarios.

Biomass gasification represents not only a clean energy solution but also an innovative waste management strategy – especially when using animal-derived residues, manure, and food waste as feedstock. The case of the Suceava plant demonstrates that even unconventional and complex materials like organic, intestines and dejections can be effectively transformed into syngas when supported by the right technology and operational approach.

While traditional feedstocks like grain silage offer higher energy yields, organic waste materials bring unmatched environmental and economic benefits. Their use diverts pollutants from landfills and wastewater, reduces methane emissions, and recycles nutrients back into agriculture through the residual ash. Moreover, these materials are locally abundant, low-cost, and continuously generated, making them ideal for sustainable energy production in both urban and rural settings.

2. TECHNOLOGIES AND RAW MATERIALS FOR THE PRODUCTION OF BIOGAS

Journal of Marine Technology and Environment
DOI:10.53464/JMTE.02.2025.11
ISSN (Print): 1844-6116
ISSN (Online): 2501-8795
https://www.jmte.eu

Anaerobic fermentation is the process by which bacteria decompose organic matter in the absence of oxygen, typically over a period ranging from 20 to 40 days.

Gasification is a partial oxidation process that converts carbonaceous materials (e.g., biomass) into *syngas* (a mixture of CO, H_2S, CH_4, and CO_2) at high temperatures (700–1500°C). The process occurs in four stages:

1. Drying (<200°C): Moisture evaporates from the feedstock.
2. Pyrolysis (200–700°C): Volatiles are released, leaving solid char and tars.
3. Oxidation (exothermic): Char reacts with O_2 to produce CO_2 and heat.
4. Reduction (endothermic): CO_2 and H_2O react with char to form CO and H_2.

Key reactions:

- $C+O_2 \rightarrow CO_2C+O_2 \rightarrow CO_2$ (oxidation)
- $C+CO_2 \rightarrow 2COC+CO_2 \rightarrow 2CO$ (Boudouard reaction)
- $C+H_2O \rightarrow CO+H_2C+H_2O \rightarrow CO+H_2$ (steam reforming).

The choice of gasifying agent (air, O_2, or steam) influences syngas composition. For instance, steam enhances H_2 production, while air introduces N_2, diluting the gas.

Several gasification technologies have been developed to maximize energy yields and reduce pollutant formation. Fixed-bed gasifiers operate at relatively low temperatures and are well suited for small-scale applications. Their simple design, however, may result in tar production, necessitating downstream cleaning. Fluidized-bed gasifiers offer better heat distribution and temperature control, fluidized beds are ideal for larger-scale systems. Their dynamic operation helps reduce tar content, although ash agglomeration can sometimes be challenging. Plasma gasifiers: by using high-energy plasma arcs, these gasifiers achieve nearly complete biomass conversion with minimal tar formation. They have higher capital costs but can produce syngas of exceptional quality for advanced applications [4,5].

In the pursuit of a sustainable and circular energy system, the use of organic waste feedstocks-especially zoogenic biomass, manure, and expired food-offers exceptional environmental, economic, and energy benefits [6]. While grain silage (commonly stored in silos) remains a valuable source of biomass.

Grain silage provides a predictable, energy-rich feedstock with relatively high gas yield per ton, thanks to its lignocellulosic content. However, organic waste holds far greater value per ton when considering its origin: it's free, renewable, and solves a pollution problem [7].

Animal-based feedstocks contain higher levels of nitrogen and sulfur, primarily from proteins and amino acids in the tissues and feces. When gasified, these elements form ammonia (NH_3) and hydrogen sulfide (H_2S), which must be removed from the syngas to prevent corrosion, emissions issues, and damage to gas engines[8]. This imposes additional costs for gas cleaning systems, such as scrubbers or catalytic converters, that are often not required when using plant-based feedstocks like silage. In contrast, syngas derived from silage contains minimal contaminants and generally requires only basic filtration, resulting in simpler downstream processing and lower maintenance [8,9].

Grain silage offers a consistent feedstock, often produced and stored under controlled conditions, ensuring uniform size, moisture, and energy content. This predictability enhances reactor stability and allows for steady-state operation with minimal fluctuation in syngas quality. Organic waste, however, is more heterogeneous [8]. Zoogenic biomass, leftovers, or manure may vary in composition depending on the season, diet, or source. Yet, with good preprocessing, blending, and experience-as demonstrated at Suceava-the system can adapt to these variations with minimal efficiency losses.

The environmental case for using animal remains**,** manure, and expired food is extremely strong. These materials are otherwise pollutants-emitting methane, ammonia, or leaching nutrients into water systems. Gasification prevents these emissions and recovers energy that would otherwise be lost. Moreover, the residual ash can be returned to agriculture as a pathogen-free, mineral-rich fertilizer, closing the nutrient loop. By contrast, silage-especially when grown specifically for energy-uses land, fertilizers, and irrigation that may compete with food production. When it comes from agricultural surplus or crop residues, however, its impact is lower [10,11].

Economically, grain silage is more expensive per ton due to the land, cultivation, and harvesting involved-especially when it's not a byproduct but a dedicated energy crop. Organic waste often comes at no cost or even generates income (e.g., through tipping fees or waste management contracts). This makes it financially attractive, especially for cities and municipalities trying to lower operating costs [12,13].

Currently, biogas production systems present a set of challenges specific to the context of organic waste processing [14]:

- Waste Logistics and Preprocessing: collecting, sorting, and preprocessing animal dejections and food waste from urban centers require organized municipal systems. Moisture reduction and contaminant separation (plastics, metals) are crucial to ensure feedstock compatibility with gasifiers;
- Pollutant Management: high-nitrogen and sulfur content in animal and food waste leads to increased levels of NH_3 and H_2S in the syngas. Cities implementing such systems will need to

Journal of Marine Technology and Environment
DOI:10.53464/JMTE.02.2025.11
ISSN (Print): 1844-6116
ISSN (Online): 2501-8795
https://www.jmte.eu

invest in efficient gas cleaning technologies to meet emissions regulations;
- Public Acceptance and Policy Frameworks: the idea of using slaughterhouse waste and expired food for energy may face public skepticism. Clear communication of environmental benefits and strong local policy incentives are essential to gain support and attract investment;
- Infrastructure and Funding: municipalities need access to capital and technical expertise to develop waste-to-energy infrastructure.

Looking ahead, advancements in modular gasification systems, feedstock pretreatment technologies, and emissions capture (e.g., biochar sequestration or carbon capture) could make waste-based syngas plants more feasible and attractive for urban deployment.

3. CASE STUDY:MOARA-SUCEAVA BIOGAS PLANT

The biogas plant is located in the commune of Moara - Suceava County, in proximity to several livestock and agricultural farms, as well as near the municipal solid waste landfill of Suceava (Figure 1).[1] The biogas produced is energetically valorised in a cogeneration plant equipped with thermal engines, generating both electricity and heat.

At the time of commissioning in 2014, the cogeneration facility primarily utilized agricultural residual biomass as feedstock: approximately 97% maize silage, with the remainder consisting of agricultural waste and animal manure. In subsequent years, the plant successfully transitioned to anaerobic digestion of organic waste originating from the food industry, including expired or non-compliant food products collected from restaurants, hotels, markets, slaughterhouses, ice cream factories, dairy producers, and beverage manufacturers.

Figure 1 Moara-Suceava Biogas Plant [1]

The technical specifications of the cogeneration units and their design performance parameters are detailed in Table 1.

Table 1. Technical Specifications of the Cogeneration Plant

No. crt.	Properties	Value
1	Installed electric power	2 x 1487 kWe
2	Installed thermal power	2 x 1472 kWt
3	Biogas consumption at nominal load	784 Nm^3/h
4	Heating value of biogas	4.42 kWh/Nm^3
5	Engine type (internal combustion engine)	JMS 420GS-B25
6	Engine Supplier	Jenbacher-Austria

The biogas production system operates continuously within the fermentation reactors, functioning 365 days a year. Once initiated, the fermentation process must not be interrupted except in exceptional cases, as frequent shutdowns incur significant costs that adversely affect the company's business model. The cogeneration units operate for 16 hours per day, from 7:00 AM to 11:00 PM, delivering electricity to the National Energy System (SEN) during peak demand periods. If the cogeneration plant is inactive for more than 8 hours a day, the excess biogas (which cannot be stored in the gas reservoir) is flared off using a combustion flare. The biogas storage tank has a capacity of 5,000 m^3.

The typical composition of biogas generated via anaerobic digestion is as follows:

- 50–75% Methane (CH_4)
- 24–49% Carbon dioxide (CO_2)
- 0–10% Nitrogen (N_2)
- 0–3% Hydrogen sulfide (H_2S)
- 0–1% Hydrogen (H_2)
- 0–2% Oxygen (O_2).

Prior to combustion in the cogeneration units, sulphur compounds are removed in a dedicated desulfurization installation to prevent corrosion and ensure combustion efficiency.

In Table 2 there is presented a comparative analysis of biogas production and lower heating value based on different feedstocks: organic waste from the food industry compared to agricultural residual biomass (corn silage and animal dejections).

Table 2. Biogas production

Year	Raw material	Mass of raw input material	Biogas		Lower heating value	Specific biogas yield
		Tm	Nm^3	MWh	kWh/Nm^3	Nm^3/kg
20	Biodegra	41146.	37938	22223.	5.86	0.092

Journal of Marine Technology and Environment
DOI:10.53464/JMTE.02.2025.11
ISSN (Print): 1844-6116
ISSN (Online): 2501-8795
https://www.jmte.eu

24	dable	3	20	49		
2023	waste generated by agro-food industry	30940.417	4133700	23999.03	5.81	0.134
2022		32177.231	3187740	19758.04	6.20	0.099
2018	Agricultural residual biomass (corn)	38410.070	7094611	33116.23	4.67	0.185
2017		43661.420	7761078	34924.85	4.50	0.178
2016		43367.050	7333293	35996.59	4.91	0.169

When processing organic waste from the food industry, the specific biogas yield ranges between 0.092 and 0.134 Nm^3 /kg, with a corresponding lower heating value between 5.81 and 6.20 kWh Nm^3 /kg.

In contrast, the use of agricultural biomass results in a higher specific biogas yield, ranging form 0.169 to 0.185 Nm^3 /kg, resembling a lower heating value between 4.50 and 4.91 Nm^3 /kg.

Although the silage scenario demonstrates a higher gas yield per unit mass, the difference is not as dramatic as expected: gas output with organic and animal waste reaches over 60% of the output obtained with silage, despite significantly higher moisture and ash content. This proves that with proper system adjustments and pre-processing (mainly drying), even "low-grade" feedstocks like zoogenic biomass or food waste can achieve solid energy recovery performance, with a reduced environmental footprint.

4. CONCLUSIONS

The transition towards renewable energy has unveiled biogas as a sustainable solution that simultaneously addresses two of the most pressing challenges of modern society: waste management and the generation of clean energy. The production of biogas from organic waste is a perfect example of a circular economy, where the waste of an entire industry is transformed into clean energy.

In addition to the production of electricity and heat, biogas also yields a valuable by-product known as digestive, which can be used as an organic fertilizer in agriculture.

Despite these considerable advantages, the production and utilization of biogas also presents significant challenges that cannot be overlooked. For instance, the process requires careful management and specialized technical expertise to maintain optimal efficiency, while fluctuations in the quality and availability of feedstock can significantly impact output.

Moreover, the rigorous control of odours and potentially harmful emissions constitutes an essential component of the process, as inadequate management could lead to negative consequences for the quality of life in nearby communities.

The biogas plant in Moara, Suceava County, stands as a compelling example of how fluidized bed gasification technology can be adapted to a wide range of feedstocks, even though the synthetic gas derived from waste requires thorough purification, due to its complex and potentially polluting composition.

The modest drop in gas volume from waste-based feedstock is compensated by lower input costs and environmental gains. When considering the avoided cost of landfill or wastewater treatment, the economics become even more favourable. Future biogas valorisation should be directed towards catalytic gasification in order to enhance efficiency and reduce tar and ammonia emissions.

5. REFERENCES

[1] International Energy Agency, 2020, *Modern Bioenergy: Statistics and Trends*. Available online: https://www.iea.org/reports/modern-bioenergy

[2] IRENA (2023), *Renewable Energy Outlook*, International Renewable Energy Agency. Available online: https://www.irena.org

[3] Schilling, C., Mola-Yudeg, B., Marinescu, M., Gaston, C., Röser, D., 2025, *Biomass Gasification as a Viable Alternative for Small-scaled Combined Heat and Power Technologies in Remote Communities in Canada*, BioEnergy Research, vol. 18, no. 2, pp. 345–360.

[4] T. L. Hsieh et al., 2018, *Chemical looping gasification for producing high purity, H2-rich syngas in a cocurrent moving bed reducer with coal and methane cofeeds*, Ind. Eng. Chem. Res., vol. 57, no. 7, pp. 2461–2475.

[5] Toor, S.S., Rosendahl, L., Rudolf, A., 2011, *Hydrothermal liquefaction of biomass: A review of subcritical water technologies*, în „Energy”, vol. 36, nr. 5, pag. 2328–2342.

[6] L. Sánchez-Martín et al. (2022), *Cost model for biogas and biomethane production in anaerobic digestion and upgrading*. Case study: Castile and Leon, Materials, vol. 16, no. 1, p. 359.

[7] K. O. Olatunji, N. A. Ahmed, and O. Ogunkunle (2021), *Optimization of biogas yield from lignocellulosic materials with different pretreatment methods: A review,* Biotechnol. Biofuels, vol. 14, pp. 1–34.

[8] European Biogas Association (2024), *Gasification: Diversification of biomass processing and waste utilisation,* Rep. EBA-Gasification, Dec. [Online]. Available: https://www.europeanbiogas.eu

[9] Livestock and Poultry Environmental Learning Community (2019), *What is gasification of manure?*. Available online: https://lpelc.org/what-is-gasification-of-manure

DOI:10.53464/JMTE.02.2025.11
ISSN (Print): 1844-6116
ISSN (Online): 2501-8795
https://www. jmte.eu

[10] U. R. Fritsche, R. E. H. Sims, and A. Monti (2010), *Direct and indirect land-use competition issues for energy crops and their sustainable production—An overview,* Biofuels, Bioprod. Bioref., vol. 4, no. 6, pp. 692–704, doi: 10.1002/bbb.258.

[11] Water Industry Journal (2025), *Turning municipal organic waste into clean energy and profit*. Available online: https://www.waterindustryjournal.co.uk/turning-municipal-organic-waste-into-clean-energy-and-profit

[12] A. Enescu and E. Diaconu (2018), *Cogeneration plant on biomass-case study*, J. Environ. Eng., vol. 1, no. 1, pp. 2–5.

[13] C. Mateescu and A. D. Dima (2022), *Critical analysis of key barriers and challenges to the growth of the biogas sector: A case study for Romania,* Biomass Convers. Bioref., vol. 12, no. 12, pp. 5989–6002.

[14] Y. Gao et al. (2023), *Syngas production from biomass gasification: Influences of feedstock properties, reactor type, and reaction parameters*, ACS Omega, vol. 8, no. 35, pp. 31620–31631.