IJETIR
ISSN (Online) 2583-0554

Impact Factor: 5.731

International Journal of Emerging Technologies and Innovative Research (IJETIR)

Volume 5, Issue 3, March 2025

A Review on Biogas Production

Biplab Roy[1] and Joydeep Das[2]
Department of Chemical Engineering[1,2]
Shree Dhanvantary College of Engineering & Technology, Surat, Gujarat, India
biplab.diatm24@gmail.com, joydeep17590@gmail.com

Abstract: *Biogas production has gained global attention as a sustainable and renewable energy source, contributing to waste management, energy security, and greenhouse gas reduction. This review explores the fundamental principles, feedstock types, microbial processes, and technological advancements in anaerobic digestion for biogas generation. Various factors influencing biogas yield, such as substrate composition, temperature, pH, and retention time, are analyzed. Additionally, recent innovations in biogas upgrading, storage, and utilization are discussed. Challenges related to process optimization, economic viability, and policy frameworks are highlighted, along with potential solutions for improving efficiency and scalability. The review underscores the role of biogas in circular economy strategies and its potential in achieving global renewable energy targets.*

Keywords: Anaerobic digestion, Feedstock, Biogas, Sustainability, Renewable energy

I. INTRODUCTION

Biogas production has emerged as a sustainable solution for renewable energy generation and organic waste management. It involves the anaerobic digestion of organic materials such as agricultural waste, food waste, manure, and sewage sludge, leading to the production of methane-rich biogas and a nutrient-rich digestate (Surendra et al., 2014). This process not only provides an alternative to fossil fuels but also contributes to environmental sustainability by reducing greenhouse gas emissions and minimizing waste disposal challenges (Weiland, 2010).

The increasing global energy demand, coupled with concerns over climate change and fossil fuel depletion, has driven extensive research into biogas technology. Several factors influence biogas production efficiency, including feedstock composition, microbial community dynamics, temperature, pH, and hydraulic retention time (Angelidaki et al., 2011). Recent advancements in anaerobic digestion technologies, such as co-digestion, pre-treatment methods, and biogas upgrading techniques, have further enhanced the viability of biogas as a renewable energy source (Mata-Alvarez et al., 2014).

Figure 1 illustrates that the diverse applications of biogas technology provide a versatile alternative for generating the necessary energy for industrial or social sectors. Biogas is mostly utilized in combined heat and power (CHP) plants, hydrogen manufacturing facilities, and sophisticated energy systems like fuel cells.

Table 1 presents the biogas facilities, upgrading units, and their respective upgrading capacity in selected EU nations.

Country	Biogas Plants	Biogas upgrading plants	Biogas capacity
Germany	94	120	204,082
Italy	1264	1	540
Netherlands	211	16	16,720
UK	-	-	18,957
Switzerland	-	-	6310

This review explores the principles of biogas production, factors affecting efficiency, technological advancements, and the potential applications of biogas in the energy sector. Additionally, it highlights the environmental and economic benefits associated with biogas utilization and its role in achieving sustainable development goals.

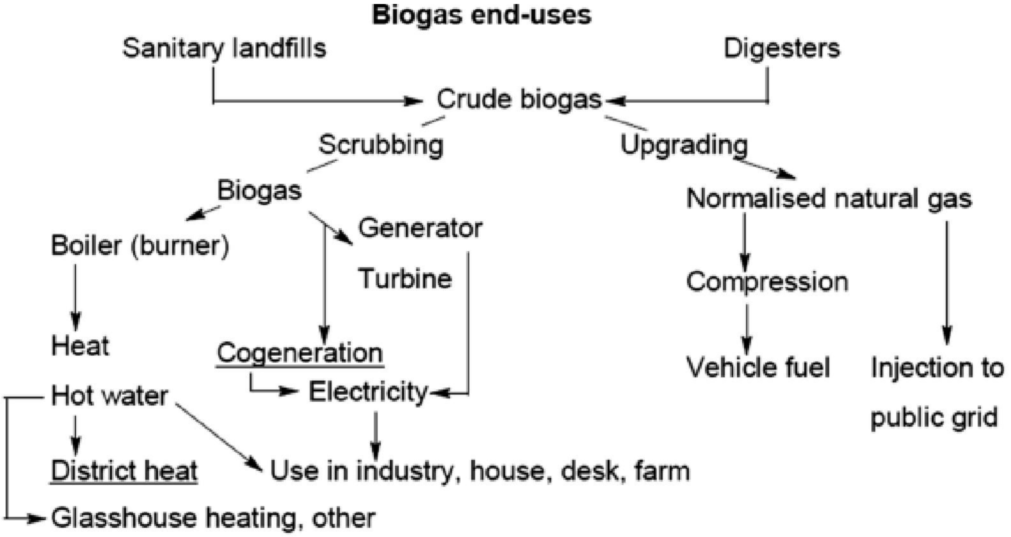

Fig. 1 Overview of biogas uses

Biogas Production Process

Biogas production occurs through anaerobic digestion (AD), a biological process in which organic material is broken down by microorganisms in the absence of oxygen. This process consists of four main stages:

1. Hydrolysis: In the first stage, complex organic polymers such as carbohydrates, proteins, and lipids are broken down into simpler molecules like sugars, amino acids, and fatty acids by hydrolytic bacteria. This step is essential for making the organic material accessible for further microbial processing (Appels et al., 2008).

2. Acidogenesis: During acidogenesis, fermentative bacteria convert the hydrolyzed products into organic acids, alcohols, hydrogen, and carbon dioxide. This stage also produces volatile fatty acids (VFAs) such as acetic acid, propionic acid, and butyric acid (Mao et al., 2017).

3. Acetogenesis: Acetogenic bacteria further break down the VFAs and other intermediate compounds into acetic acid, hydrogen, and carbon dioxide. These products serve as key substrates for methanogenic microorganisms in the final stage (Angelidaki et al., 2003).

4. Methanogenesis: In the final stage, methanogenic archaea convert acetic acid, hydrogen, and carbon dioxide into methane (CH_4) and carbon dioxide (CO_2). This biogas can be used as a renewable energy source for heating, electricity, and transportation (Weiland, 2010).

Figure 2 describes the different stages of biogas production during AD.

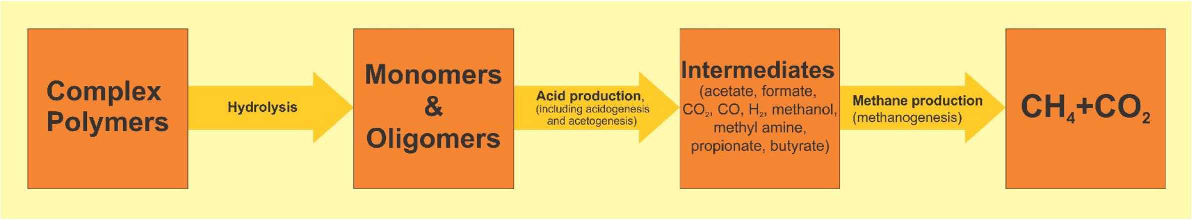

Fig. 2 The degradation process during AD

Feedstock for Biogas Production

The choice of feedstock plays a crucial role in the efficiency, yield, and composition of the produced biogas. Various organic materials can be used, ranging from agricultural residues to municipal solid waste.

1. Agricultural Residues: Agricultural residues, such as crop residues, animal manure, and agro-industrial waste, are widely used for biogas production. Animal manure, particularly from cattle, pigs, and poultry, is rich in nitrogen and enhances microbial activity, improving methane production (Li et al., 2020).

2. Energy Crops: Energy crops, such as maize, sorghum, and switchgrass, are cultivated explicitly for biogas production. These crops have high carbohydrate content, which facilitates higher methane yields during anaerobic digestion (Weiland, 2010).

3. Organic Waste from Households and Industries: Food waste from households and food processing industries is another significant feedstock. This waste is rich in easily degradable organic matter, leading to high biogas yields (Zhang et al., 2017).

4. Municipal Solid Waste (MSW): Municipal solid waste includes organic fractions such as garden waste, food waste, and paper. Proper pre-treatment is necessary to remove contaminants before anaerobic digestion (Kothari et al., 2014).

5. Sewage Sludge: Sewage sludge from wastewater treatment plants contains a high proportion of biodegradable organic material. It is a common feedstock for biogas production in urban settings (Appels et al., 2011).

6. Industrial Wastewater: Industrial wastewater from dairy, brewery, and pulp industries contains high concentrations of organic substances that can be utilized for biogas generation (Mata-Alvarez et al., 2014).

Factors affecting biogas production

Biogas production is influenced by several factors that impact microbial activity, substrate decomposition, and gas yield. The efficiency of the anaerobic digestion (AD) process depends on optimizing these factors to maximize methane production. The key factors affecting biogas production include:

1. Substrate Composition: The type and composition of the organic material being digested play a crucial role in biogas yield. High carbon-to-nitrogen (C/N) ratios, lignocellulosic materials, and inhibitory compounds can affect microbial metabolism and methane production (Li et al., 2019).

2. Temperature: The anaerobic digestion process occurs optimally in mesophilic (35–40°C) or thermophilic (50–60°C) conditions. Temperature fluctuations can hinder microbial efficiency, reducing biogas yield.

3. **pH Levels**: The optimal pH range for anaerobic digestion is 6.5–7.5. Deviations from this range can inhibit methanogenic bacteria, leading to lower biogas production (Wang et al., 2021).

4. **Retention Time**: The hydraulic retention time (HRT) and solid retention time (SRT) influence substrate degradation and methane production. Longer retention times generally increase biogas yield, but excessive retention may lead to system inefficiency (Karthikeyan et al., 2018).

5. **Microbial Population**: The presence and balance of hydrolytic, acidogenic, acetogenic, and methanogenic bacteria are essential for efficient biogas production. Any imbalance in microbial consortia can lead to process instability (Raposo et al., 2011).

6. Organic Loading Rate (OLR): The organic loading rate determines the amount of substrate fed into the digester. Overloading can cause acidification, while underloading results in lower biogas yield (Mata-Alvarez et al., 2000).

7. Inhibitory Substances: Toxic compounds such as ammonia, sulfides, and heavy metals can negatively affect microbial activity, leading to reduced biogas production.

8. Agitation and Mixing: Proper mixing ensures uniform substrate distribution and prevents the formation of scum layers that can reduce biogas production efficiency (Weiland, 2010).

Recent Advances in Biogas Technology

Biogas technology has witnessed significant advancements in recent years, driven by the need for sustainable energy solutions and efficient waste management. Innovations in biogas production, purification, and utilization have enhanced the efficiency, affordability, and environmental impact of the technology. This article explores the latest developments in biogas technology, including improved feedstock processing, advanced digester designs, and novel upgrading techniques.

1. Improved Feedstock Utilization: Recent studies have focused on optimizing feedstock composition to enhance biogas yield. Co-digestion of various organic wastes, such as agricultural residues, food waste, and sewage sludge, has been shown to improve methane production (Mao et al., 2017). Pre-treatment techniques, including hydrothermal, enzymatic, and ultrasonic methods, have also been employed to break down complex organic matter, increasing biogas yield.

2. Advanced Digester Designs: Innovations in anaerobic digesters have led to increased efficiency and stability of biogas production. High-rate digesters, such as Upflow Anaerobic Sludge Blanket (UASB) and Anaerobic Membrane Bioreactors (AnMBRs), offer better organic matter degradation and higher methane production rates. Additionally, temperature-phased anaerobic digestion (TPAD) has been introduced to optimize microbial activity and enhance digestion efficiency (Appels et al., 2011).

3. Biogas Upgrading and Purification: Biogas purification is essential to remove impurities like carbon dioxide (CO_2), hydrogen sulfide (H_2S), and moisture, making it suitable for grid injection and vehicle fuel applications. Membrane separation, pressure swing adsorption (PSA), and water scrubbing techniques have been developed to enhance biogas quality. Recent advances include the use of bioelectrochemical systems for simultaneous purification and methane enrichment (Angelidaki et al., 2018).

4. Integration with Renewable Energy Systems: The integration of biogas technology with other renewable energy systems, such as solar and wind, has gained traction. Hybrid energy systems that utilize biogas for base-load power generation while complementing intermittent renewables improve energy reliability and sustainability (Kougias et al., 2019). Additionally, power-to-gas (P2G) technology, which converts surplus renewable electricity into methane via microbial electrolysis, has emerged as a promising innovation.

5. Digitalization and Smart Monitoring: The adoption of Internet of Things (IoT)-based monitoring systems has improved process control and efficiency in biogas plants. Real-time sensors and data analytics are used to monitor parameters such as pH, temperature, and biogas composition, enabling predictive maintenance and optimized operation. Machine learning algorithms are also being employed to enhance process efficiency and predict failures (Deepanraj et al., 2021).

Environmental and Economic Benefits

Biogas production presents numerous environmental and economic benefits, making it a viable alternative to traditional fossil fuels. The anaerobic digestion process used in biogas production transforms organic waste into a sustainable energy source while reducing environmental pollution and promoting economic development.

Environmental Benefits

1. Waste Management and Reduction: Biogas production helps manage organic waste by utilizing agricultural residues, food waste, and animal manure. This process significantly reduces landfill waste, minimizing methane emissions from decomposing organic matter (Tiwari et al., 2021).

2. Reduction of Greenhouse Gas Emissions: The use of biogas as a fuel source replaces fossil fuels, leading to lower carbon dioxide (CO2) and methane (CH4) emissions. Methane, a potent greenhouse gas, is captured and utilized rather than released into the atmosphere (Awasthi et al., 2020).

3. Renewable Energy Source: Unlike finite fossil fuel reserves, biogas is a renewable energy source that can be continuously produced as long as organic waste is available, ensuring long-term sustainability.

Economic Benefits

1. Energy Cost Savings: Biogas can replace conventional fuels for cooking, heating, and electricity generation, reducing energy expenses for households, farms, and industries (Kothari et al., 2020).

2. Revenue Generation from Byproducts: Digestate, a byproduct of biogas production, can be sold as an organic fertilizer, adding an additional revenue stream for farmers and biogas producers (Gupta et al., 2020).

3. Energy Security and Reduced Import Dependency: Countries that rely on imported fossil fuels can enhance their energy security by adopting biogas technology, reducing dependence on volatile international energy markets.

II. CONCLUSION

Biogas production is a promising renewable energy technology that contributes to environmental sustainability and energy security. Ongoing research and technological advancements continue to improve efficiency and economic viability. Future research should focus on optimizing microbial consortia, integrating biogas with other renewable systems, and exploring novel feedstocks.

REFERENCES

[1]. Angelidaki, I., Ellegaard, L., & Ahring, B. K. (2003). Applications of the anaerobic digestion process. *Advances in Biochemical Engineering/Biotechnology, 82,* 1-33.

[2]. Angelidaki, I., Karakashev, D., Batstone, D. J., Plugge, C. M., & Stams, A. J. M. (2011). Biomethanation and its potential. *Methods in Enzymology, 494,* 327-351. https://doi.org/10.1016/B978-0-12-385112-3.00016-0

[3]. Angelidaki, I., Treu, L., Tsapekos, P., Luo, G., Campanaro, S., Wenzel, H., & Kougias, P. G. (2018). Biogas upgrading and utilization: Current status and perspectives. *Biotechnology Advances, 36(2),* 452-466.

[4]. Appels, L., Baeyens, J., Degrève, J., & Dewil, R. (2008). Principles and potential of the anaerobic digestion of waste-activated sludge. *Progress in Energy and Combustion Science, 34(6),* 755-781.

[5]. Awasthi, M. K., Sarsaiya, S., Patel, A., Juneja, A., Singh, R. P., & Yan, B. (2020). Biogas production from organic waste: Recent advancements and challenges. *Renewable Energy, 150,* 587-600.

[6]. Deepanraj, B., Sivasubramanian, V., & Jayaraj, S. (2021). Optimization of biogas production through predictive modeling and machine learning algorithms. *Renewable Energy, 169,* 1-14.

[7]. Gupta, P., Rathore, V., & Pandey, S. (2020). Role of biogas in sustainable agriculture and energy security. *BioEnergy Research, 13(3),* 745-758.

[8]. Karthikeyan, O. P., Trably, E., Mehariya, S., Bernet, N., & Steyer, J. P. (2018). Biomethane production from biomass and waste: Current status and future perspectives. *Bioresource Technology, 247,* 1085-1093.

[9]. Kougias, P. G., Treu, L., Benavente, D. P., Campanaro, S., & Angelidaki, I. (2019). Ex-situ biogas upgrading and enhancement in a hybrid power-to-methane reactor. *Bioresource Technology, 278,* 253-258.

[10]. Kothari, R., Tyagi, V. V., Pathak, A., & Pandey, A. (2014). Waste to energy: a way from municipal solid waste to sustainable energy. *Renewable and Sustainable Energy Reviews, 29*, 198-208.

[11]. Kothari, R., Tyagi, V. V., & Pathak, A. (2020). Waste to energy: A sustainable approach for renewable energy generation*. Renewable and Sustainable Energy Reviews, 120,* 109651.

[12]. Li, Y., Park, S. Y., & Zhu, J. (2019). Solid-state anaerobic digestion for methane production from organic waste. *Renewable and Sustainable Energy Reviews, 15(1),* 821-826.

[13]. Li, Y., Park, S. Y., & Zhu, J. (2020). Solid-state anaerobic digestion for methane production from organic waste. *Renewable and Sustainable Energy Reviews, 15*(1), 821-826.

[14]. Mao, C., Feng, Y., Wang, X., & Ren, G. (2017). Review on research achievements of biogas from anaerobic digestion. *Renewable and Sustainable Energy Reviews, 45,* 540-555.

[15]. Mata-Alvarez, J., Macé, S., & Llabrés, P. (2014). Anaerobic digestion of organic solid wastes. An overview of research achievements and perspectives. *Bioresource Technology, 74(1),* 3-16. https://doi.org/10.1016/S0960-8524(00)00023-7

[16]. Raposo, F., Borja, R., Martín, M. A., Martín, A., de la Rubia, M. A., & Rincón, B. (2011). Influence of inoculum-substrate ratio on the anaerobic digestion of sunflower oil cake in batch mode: Process performance and kinetic modeling. *Renewable Energy, 36(2),* 632-641.

[17]. Surendra, K. C., Takara, D., Hashimoto, A. G., & Khanal, S. K. (2014). Biogas as a sustainable energy source for developing countries: Opportunities and challenges. *Renewable and Sustainable Energy Reviews, 31,* 846-859. https://doi.org/10.1016/j.rser.2013.12.015

[18]. Tiwari, P., Kumar, P., & Malik, A. (2021). Impact of biogas technology on waste management and climate change mitigation. *Environmental Science & Technology, 55(5),* 2345-2353.

[19]. Wang, M., Zhao, Z., & Liu, H. (2021). Effects of pH and temperature on anaerobic digestion of kitchen waste: Methane production and microbial community structure. *Journal of Cleaner Production, 279,* 123456.

[20]. Weiland, P. (2010). Biogas production: Current state and perspectives. *Applied Microbiology and Biotechnology, 85(4),* 849-860. https://doi.org/10.1007/s00253-009-2246-7

[21]. Zhang, C., Su, H., Baeyens, J., & Tan, T. (2017). Reviewing the anaerobic digestion of food waste for biogas production. *Renewable and Sustainable Energy Reviews, 38*, 383-392.