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Biogas and its Utilization of Various sector: A Review

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ABSTRACT:. This report investigates biogas production and its diverse applications across various fields. Biogas, primarily composed of methane (CH_4) and carbon dioxide (CO_2), is generated through anaerobic digestion of organic waste such as agricultural residue, sewage, and food waste. The study explores several biogas production methods, including batch and continuous reactors, and compares the efficiency of different feedstocks. The principle of anaerobic digestion involves microbial breakdown of organic matter in oxygen-free conditions, producing biogas and digestate, a nutrient-rich by-product.

Key applications include electricity generation, cooking fuel, automotive fuel (compressed biogas), and waste management. Results indicate that biogas systems offer environmental benefits, such as greenhouse gas reduction, and waste minimization, and economic advantages like cost savings and renewable energy production. The study concludes that biogas is a viable solution for sustainable energy and circular economy, with significant potential in rural and urban sectors.

I. INTRODUCTION

Biogas is a renewable energy source produced through the anaerobic digestion of organic materials such as agricultural waste, animal manure, food scraps, and sewage. As a sustainable alternative to fossil fuels, biogas plays a key role in reducing greenhouse gas emissions and supporting waste management. The main components of biogas are methane (CH_4) and carbon dioxide (CO_2), with traces of hydrogen sulfide (H_2S). Its production not only generates energy but also provides a nutrient-rich byproduct, digestate, which can be used as organic fertilizer.

The anaerobic digestion process involves microorganisms breaking down organic matter in the absence of oxygen through four stages: hydrolysis, acidogenesis, acetogenesis, and methanogenesis. The resulting biogas can be used for various purposes. It supports electricity and heat production through combined heat and power (CHP) systems, used in industries and farms. When purified, biogas becomes compressed biogas (CBG), which serves as a cleaner automotive fuel alternative to compressed natural gas (CNG). In rural areas, it provides an eco-friendly cooking fuel, reducing indoor air pollution and deforestation.

Biogas systems also play an important role in waste management by reducing emissions from landfills and efficiently treating organic waste. The digestate from biogas plants offers sustainable agricultural benefits by enhancing soil fertility and reducing dependence on chemical fertilizers. Many industries, such as food processing and breweries, integrate biogas systems to manage waste while meeting their energy needs.

In addition to environmental benefits, biogas production creates economic opportunities, especially in rural areas, by generating jobs and promoting energy security. By capturing methane emissions that would otherwise escape into the atmosphere, biogas helps combat climate change and supports global sustainability goals. Its versatile applications in energy, transportation, agriculture, and industry make biogas an essential part of the transition to cleaner energy and a circular economy. From these different feedstock used and compare the amount of biogas generated.

II. LITERATURE REVIEW

Ahmad Rafiee et al.'s review focuses on the entire biogas value chain, from production to end-use, with particular attention to upgrading methods. Upgrading biogas is essential to convert it into biomethane by removing impurities like

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carbon dioxide and hydrogen sulfide. The study compares physicochemical methods such as water scrubbing and pressure swing adsorption with biological techniques, including microalgae-based processes.

A significant part of the review analyzes the economic feasibility and environmental impact of these technologies. Biological methods show promise due to their lower energy consumption, but scalability remains a challenge. The research highlights the need for integrated solutions to optimize both biogas yield and cost efficiency across sectors.

Kabeyi et al. discuss biogas production and its critical role in the sustainable energy transition. They highlight the competitive advantages of biogas due to its diverse feedstock, potential applications, and the increasing global capacity for biogas electricity generation. The authors examine various conversion methods for biogas, including its use in combustion engines, fuel cells, and as a source for biofuels. Overall, the review underscores biogas's potential to contribute significantly to sustainable energy systems and reduce reliance on fossil fuels.

Abanades et al. the authors examine biogas production, usage, and the legislative frameworks governing these processes across various countries. The review emphasizes the importance of biogas as a renewable energy source and discusses the efficiency of different production methods, including anaerobic digestion. Furthermore, it highlights the regulatory challenges and incentives that affect biogas implementation, advocating for a coherent legal framework to support its development. This comprehensive analysis underscores the potential of biogas to contribute significantly to sustainable energy goals globally.

Khaled Obaideen et al. provide a comprehensive overview of biogas production, highlighting its status, advantages, disadvantages, and the impurities often found in biogas. The authors identify significant barriers to biogas production and connect these challenges to the Sustainable Development Goals (SDGs), demonstrating how biogas can contribute to various SDGs, including those related to energy, environment, and waste management.

They developed 58 indicators to evaluate biogas's impact on achieving these goals, emphasizing its potential to foster a circular economy by utilizing organic waste and reducing environmental impacts. The review concludes that biogas presents a sustainable energy solution and aligns with broader environmental and economic objectives.

Lucia Pera et al. the author examines the composition of trace contaminants in biogas, such as hydrogen sulfide (H_2S), ammonia, volatile organic compounds (VOCs), and siloxanes, is highly dependent on the type of biomass feedstock used. Agricultural residues, organic waste, and animal manure all contribute unique chemical components that affect the quality of the gas. For example, manure can introduce high levels of ammonia, while municipal organic waste might release siloxanes that can damage equipment. This variability requires careful management to ensure biogas meets performance and environmental standards.

Contaminants pose challenges by corroding equipment, reducing efficiency, and creating harmful emissions. H_2S, for instance, can corrode metal parts, while siloxanes form abrasive deposits in engines, reducing their lifespan. Technologies such as scrubbing systems, adsorption filters, and biological treatment methods are used to remove these impurities, ensuring the biogas is safe and effective for energy production or upgrading to biomethane. Proper treatment not only protects equipment but also ensures that biogas systems operate sustainably and meet regulatory requirement

Yizhong Duan et al. explored the potential of using biochar-enhanced biogas slurry as a solvent in a once-through CO_2 chemical absorption process. Their research demonstrates that biochar not only improves the slurry's CO_2 absorption capacity but also increases the stability of absorbed CO_2 by promoting its conversion into bicarbonate (HCO_3^-) and carbamate. This stability reduces re-emission and enhances long-term retention of CO_2, making the system more effective.

The study shows that the efficiency of absorption varies with biochar type, with C4 plant-derived biochar outperforming C3 plant and wood biochars. The improvement is attributed to the biochar's pore volume and the elevated pH of the slurry, which facilitate greater chemical interaction with CO_2. The findings suggest that biochar-based slurries could serve as sustainable solvents in carbon capture, helping reduce CO_2 emissions in industrial applications without requiring complex regeneration processes. This method offers a cost-effective alternative for enhancing carbon sequestration and supporting climate mitigation efforts.

Raman Kumawat et al. conducted a comparative life cycle assessment (LCA) of biogas-powered and coal-powered power plants to evaluate their environmental performance and identify optimized operational strategies. Their study highlights the significant environmental benefits of biogas systems, including reduced greenhouse gas (GHG) emissions and lower pollution levels compared to coal-powered plants. Biogas plants generate energy through anaerobic digestion, utilizing organic waste, which minimizes methane release into the atmosphere. In contrast, coal plants contribute substantially to GHG emissions and environmental degradation through carbon-intensive processes.

The analysis indicates that biogas-powered systems are more sustainable over their life cycle, with fewer emissions from waste management to energy production. The study emphasizes that biogas offers a viable solution for decarbonizing the energy sector, while coal plants require extensive emission control technologies to reduce their environmental footprint. The research also points out that integrating renewable energy solutions like biogas into the power grid can play a crucial role in transitioning towards cleaner energy systems.

NurulEzza Fazlina Abu et al. explored the use of biochar derived from rubber sludge as an effective method for removing ammonia from rubber wastewater. High ammonia levels in wastewater can be detrimental to aquatic life and contribute to environmental pollution. The researchers optimized various conditions, including pH, adsorbent dosage, and contact time, to enhance the adsorption capacity of the biochar.

Their findings indicated that the rubber-sludge-based biochar successfully reduced ammonia concentrations, achieving over 80% removal efficiency under optimal conditions. Moreover, the study highlighted the biochar's potential to enhance biogas production during anaerobic digestion of wastewater. This dual benefit demonstrates the viability of using rubber sludge as a sustainable resource for wastewater treatment while simultaneously producing renewable energy. The study contributes to the ongoing research on waste valorization, emphasizing the importance of innovative solutions in addressing environmental challenges associated with industrial wastewater.

Overall, this research not only offers a promising approach to ammonia removal but also aligns with sustainable development goals by promoting waste recycling and renewable energy generation

Pengfei Hu et al. focus on the distributed dynamic economic dispatch of a multi-microgrid system that integrates biogas, wind, solar, and hydrogen energy sources. The paper addresses the challenges of economic efficiency and reliability that often arise in isolated microgrid systems that rely on a single energy source. By considering the individual selfishness of microgrid operators, the authors developed a dynamic economic dispatch model that accommodates multiple time scales and the coupling constraints between different energy resources.

of collection phase. c) A Terminated Process based Introspection for Virtual Machines in Cloud Computing. This captured every process that was terminated and later was improvised to capture only the processes that were found doubtful.

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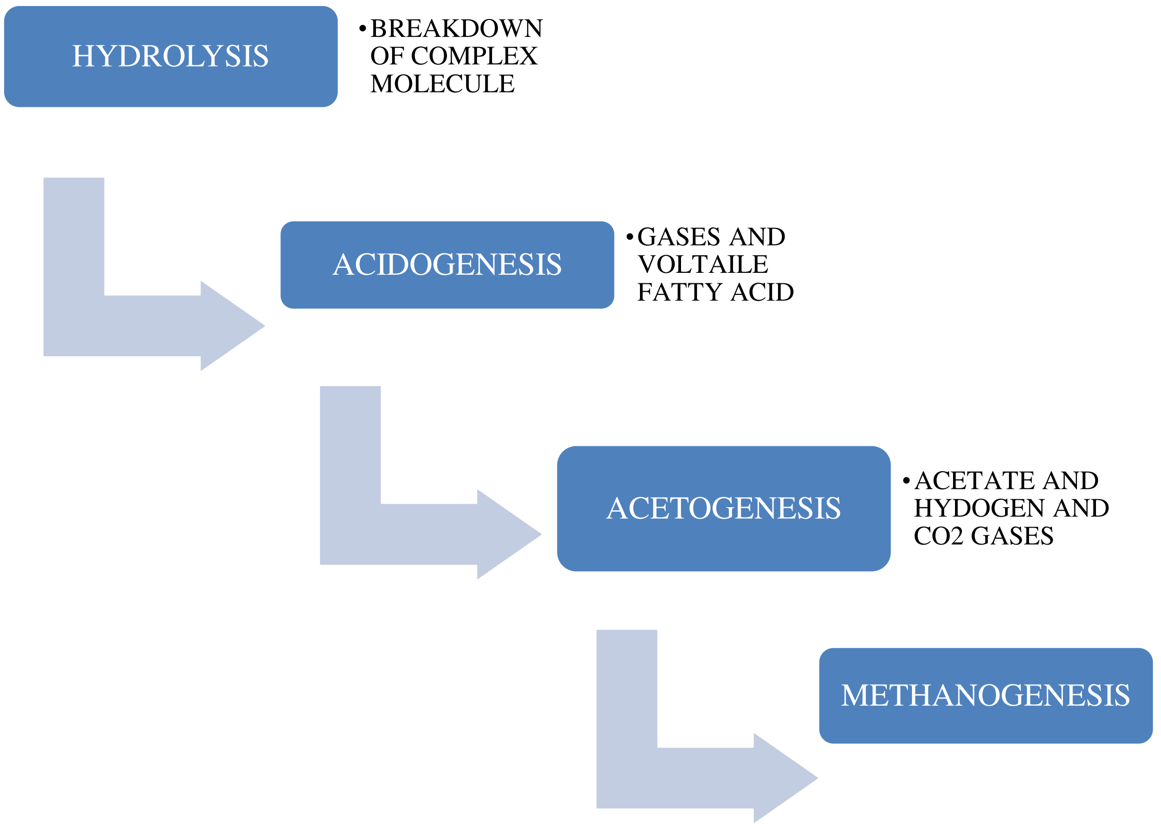
III. METHODOLOGY OF PROPOSED SURVEY



The anaerobic process for biogas production involves a series of microbial reactions that occur in the absence of oxygen. Initially, organic waste materials like food scraps, agricultural residues, or sewage sludge are fed into an anaerobic digester. This system is sealed to maintain an oxygen-free environment conducive to the microbial activity required for biogas production.

The first step in the anaerobic digestion process is the selection and preparation of the feedstock. Various organic materials can be used, including:
Agricultural residues (crop leftovers, animal manure)
Food waste (fruits, vegetables, and other kitchen scraps)
Industrial waste (brewery waste, dairy effluents)
Sewage sludge from wastewater treatment plants
Once the feedstock is selected, it must be pre-processed to optimize conditions for anaerobic digestion. This may include shredding or grinding the materials to increase their surface area, mixing different types of feedstock to create a balanced substrate, and adjusting moisture content to achieve an ideal range (typically between 50% and 70%).

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Feedstock	Values	Feedstock	Values
Cattle slurry	15-25 (10% DM)	Potatoes	276-400
Pig slurry	15-25 (8% DM)	Rye grain	283-492
Poultry	30-100 (20% DM)	Clover grass	290-390
Grass silage	160-200 (28% DM)	Sorghum	295-372
Whole wheat crop	185 (33% DM)	Grass	298-467
Maize silage	200-220 (33% DM)	Red clover	300-350
Maize grain	560 (80% DM)	Jerusalem artichoke	300-370
Crude glycerine	580-1000 (80% DM)	Turnip	314
Wheat grain	610 (85% DM)	Rhubarb	320-490
Rape meal	620 (90% DM)	Triticale	337-555
Feedstock	**Values**	**Feedstock**	**Values**
Fats	up to 1200	Oilseed rape	340-340
Nettle	120-420	Canary grass	340-430
Sunflower	154-400	Alfalfa	340-500
Miscanthus	179-218	Clover	345-350
Flax	212	Barley	353-658
Sudan grass	213-303	Hemp	355-409
Sugar beet	236-381	Wheat grain	384-426
Kale	240-334	Peas	390
Straw	242-324	Ryegrass	390-410
Oats grain	250-295	Leaves	417-453
Chaff	270-316	Fodder beet	160-180

In the **first phase**, called hydrolysis, complex organic molecules such as carbohydrates, proteins, and fats are broken down into simpler, soluble compounds like sugars, amino acids, and fatty acids. Hydrolytic bacteria release enzymes that catalyze this process, making the organic material more accessible for further degradation.

Next, in **acidogenesis,** the products of hydrolysis are converted by acidogenic bacteria into volatile fatty acids, alcohols, hydrogen gas, and carbon dioxide. This stage leads to the formation of intermediary compounds necessary for the following steps. Inoculum is a source of microorganisms required for the anaerobic digestion process. It can be derived from previously digested materials, such as digestate from an existing anaerobic digester or fresh sewage sludge. The inoculum contains methanogenic bacteria and other microorganisms that break down organic matter and produce biogas. The addition of inoculum helps establish the necessary microbial community and accelerates the digestion process. Several genera of methanogens are involved in biogas production, including "Methanobacterium," "Methanosarcina," "Methanoculleus," and "Methanobrevibacter."

Anaerobic digestion can occur in various types of reactors, including batch digesters, continuous stirred-tank reactors (CSTRs), plug-flow digesters, and covered lagoons. The choice of digester design depends on factors such as the type of feedstock, the desired retention time, and the scale of operation.

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Key operational parameters must be carefully controlled to ensure optimal biogas production:

The type of digester can vary significantly based on the application and feedstock. Batch digesters, for instance, are filled with organic material and inoculum all at once, with the entire contents removed once digestion is complete. This design is straightforward but can lead to variations in biogas yield due to inconsistent conditions. Continuous Stirred-Tank Reactors (CSTRs), on the other hand, allow for continuous feedstock input and digestate removal, maintaining steady conditions for microbial activity, making them suitable for high-throughput operations.

Plug-flow digesters feature a horizontal design where the substrate moves through the system in a plug-like manner. This configuration minimizes mixing and is particularly effective for high-solid feedstocks, such as manure, promoting efficient digestion.

Covered lagoons represent another design option, consisting of large, shallow ponds that capture biogas through a membrane cover. While these lagoons are cost-effective for managing large volumes of wastewater, they typically yield less biogas compared to enclosed digesters.

The materials used in constructing digesters can include concrete, steel, or fiberglass, selected based on factors such as durability, corrosion resistance, and the nature of the waste being processed. The digester's size is determined by the volume of organic waste it needs to accommodate, with the hydraulic retention time (HRT) being a crucial consideration. A larger digester allows for longer retention times, which can enhance biogas production.

Temperature: Anaerobic digestion occurs effectively at mesophilic (30-40°C) or thermophilic (50-60°C) temperatures. Maintaining the desired temperature range promotes the activity of specific microbial communities responsible for breaking down organic matter.

PH: The pH of the digester should be maintained between 6.5 and 8.0 to support microbial growth. If the pH falls outside this range, it may inhibit microbial activity and biogas production.

Retention Time: The hydraulic retention time (HRT) is the time the feedstock remains in the digester. Depending on the type of feedstock and digester design, HRT can range from a few days to several weeks. Longer retention times generally lead to increased biogas production.

During **acetogenesis**, the volatile fatty acids and other intermediates from acidogenesis are further broken down by acetogenic bacteria into acetic acid, along with more hydrogen and carbon dioxide. Acetate and hydrogen serve as key substrates for the final step of the process.

In **methanogenesis,** methanogenic archaea utilize acetic acid, hydrogen, and carbon dioxide to produce methane and carbon dioxide, the primary components of biogas. Methanogenesis is highly sensitive to environmental conditions, particularly pH and temperature, which must be maintained within optimal ranges to ensure efficient methane production.

Monitoring is essential to ensure the stability and efficiency of the anaerobic digestion process. Key parameters to track include:

Biogas Production Rate: Regular measurements of biogas volume can help assess digestion efficiency and detect any issues early on.

Substrate Degradation: Monitoring the reduction of organic material in the digester helps evaluate the digestion process's performance.

Microbial Activity: Techniques such as measuring volatile fatty acids (VFAs) and total ammonia nitrogen (TAN) can indicate microbial activity and the overall health of the microbial community.

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Throughout the process, the digester retains the biomass for sufficient time to allow the microorganisms to complete these reactions. The biogas produced is collected from the top of the digester and can be purified and used as a renewable energy source. The remaining digestate, rich in nutrients, can be used as fertilizer or soil conditioner, completing the cycle of waste-to-energy conversion.This process is widely used for treating various types of organic waste, including agricultural residues, food waste, sewage sludge, and industrial by-products. The biogas produced can be utilized as a renewable energy source, while the residual digestate can be used as a nutrient-rich fertilizer.

As organic matter is broken down, biogas accumulates in the headspace of the digester. This biogas primarily consists of methane (50-70%), carbon dioxide (30-50%), and small amounts of other gases (e.g., hydrogen sulfide, ammonia). Biogas can be collected and used for various applications, including:

Electricity Generation: Biogas can be burned in combined heat and power (CHP) systems to produce electricity and heat.

Heating: It can be used directly for industrial or residential settings.

Upgrading to Biomethane: Biogas can be purified to remove impurities and carbon dioxide, producing biomethane, which can be injected into the natural gas grid or used as vehicle fuel

The solid material remaining after anaerobic digestion is called digestate. This material is nutrient-rich and can be used as fertilizer or soil amendment. Proper management of digestate is essential to prevent nutrient runoff and environmental contamination. Depending on local regulations, digestate may require further treatment (e.g., composting or drying) before application to agricultural fields.

IV. CONCLUSION AND FUTURE WORK

This review highlights the use of various feedstocks for biogas production through the anaerobic digestion process. It was observed that substrates such as wheat grain, maize grain, and leaves yield higher amounts of biogas. The process of methanogenesis plays a crucial role in the generation of methane (CH_4) and carbon dioxide (CO_2), which are the primary components of biogas.

Based on these findings, we propose utilizing cow dung and green leaves as potential feedstocks to further explore their efficiency in biogas production. Our future research is to evaluate their suitability for generating electricity and producing compressed biogas for fuel applications. This review will contribute to understanding the viability of these feedstocks for sustainable energy solutions.

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