International Journal of Multidisciplinary Research and Publications
ISSN (Online): 2581-6187

Retrofitting an Existing Septic Tank for Biogas Production and Energy Use

Cathel Jane S. Pitoc[1], Dr. Lizamyl R. Laping[2]
[1]Department of Sanitary Engineering, Western Mindanao State University, Zamboanga City, Philippines -7000
[2]College of Engineering and Technology, Western Mindanao State University, Zamboanga City, Philippines -7000
Email address: xt202000100 @ wmsu.edu.ph, lizamyl.laping @ wmsu.edu.ph

Abstract**—** *This study assessed the feasibility of retrofitting a 10-year-old single-chamber septic tank for biogas recovery using low-cost materials and sensor-based monitoring. The objective was to convert an existing waste treatment structure into a functional source of renewable energy without major redesign. Structural evaluation confirmed the tank's integrity and compliance with minimum requirements of the Revised National Plumbing Code of the Philippines (2015), making it suitable for retrofitting. A biogas collection system was installed, consisting of a modified vent pipe, gas conveyance lines, filtration setup, and real-time monitoring using an Arduino-based system with methane, temperature, pressure, and airflow sensors. Over a 10-day observation period, biogas production increased from 43.2 liters on Day 1 to a peak of 100.8 liters on Day 6, with a total yield of approximately 769.68 liters. Flowrate data exhibited a distinct diurnal pattern, with maximum output recorded at 12:00 p.m. reaching 0.15 L/min. Methane concentration improved after basic filtration, increasing from 1.13–1.81 ppm to 2.43–3.96 ppm. A combustion test confirmed the biogas' usability, indicated by a pale blue flame and effective heat output. While the system demonstrated effective performance, several limitations were identified, including the short monitoring duration, the use of simplified sensor calibration methods, and the limited capacity of the gas storage system. To address these issues, it is recommended that future studies extend monitoring to capture seasonal trends, analyze biogas composition with gas chromatography, evaluate low-cost biogas burners, calibrate sensors with certified standards, conduct repeated combustion tests to assess fuel quality, and install temperature sensors inside digestion chambers for more accurate data. Overall, the study affirms that retrofitting existing septic tanks is a practical and scalable solution for decentralized biogas production and sustainable waste management, particularly in rural and underserved areas.*

Keywords**—** *Biogas collection system: Biogas production: Biogas recovery: Renewable energy: Retrofitting: Septic tank: Sustainable waste management.*

I. INTRODUCTION

This study explores the feasibility of retrofitting existing septic tanks to capture biogas as a renewable energy source. Septic tanks, especially in areas without centralized wastewater treatment, are known sources of greenhouse gas (GHG) emissions—mainly methane (CH_4) and carbon dioxide (CO_2)—due to the anaerobic breakdown of organic waste. While these emissions contribute to climate change, these emissions also present an opportunity for sustainable energy production through biogas recovery.

The research addresses the challenge of modifying conventional septic systems, which are typically not designed for energy capture. By integrating biogas collection technologies, the study aims to reduce harmful emissions and improve waste management without major structural redesigns. It evaluates technical, economic, and operational barriers to retrofitting and seeks to optimize biogas volume, methane concentration, and usability for energy purposes such as heating.

Conducted at the researcher's residence in Ayala, Zamboanga City, the study is limited in scope to one septic tank and a short monitoring period. It assesses biogas quality through combustion tests and acknowledges that results may vary with environmental and usage conditions. Nonetheless, the findings aim to support scalable solutions for renewable energy and environmental sustainability, especially in underserved and rural communities.

II. METHODOLOGY

This study aims to integrate a biogas collection system into an existing septic tank on a pilot scale, converting methane emissions into a renewable energy source. The experimental setup will evaluate the feasibility, efficiency, and performance of the retrofitted system.

A. Pre-retrofitting Assessment

The septic tank was evaluated using non-invasive techniques to determine its suitability for retrofitting. This included a visual check for damage like cracks or leaks, measuring its dimensions for biogas system compatibility, and assessing site accessibility for future equipment installation and maintenance. Structural integrity was tested by tapping the tank to detect weaknesses or voids. Its functionality was reviewed by monitoring flow patterns and checking for issues such as odors or blockages. Finally, construction and maintenance records were examined to understand the tank's age, materials, and service history. Together, these steps provided a thorough condition assessment.

B. Sensor Integration for Biogas Monitoring

To monitor biogas in a retrofitted septic tank, three sensors were used: an MQ-4 for methane detection, an AHT20+BMP280 for temperature, humidity, and pressure, and an F1031V for airflow measurement. These sensors were connected to an Arduino Uno, which handled data collection—analog inputs for the MQ-4 and F1031V, and I2C for the AHT20+BMP280. A custom Arduino program managed sensor initialization, data display, and calibration.

Field-adapted calibration included using a lighter for methane, a controlled chamber for temperature and pressure, and a fan for airflow. Although not as precise as lab setups, the system offered a practical, low-cost solution for real-world environmental monitoring.

C. Biogas Filtration System Setup

The biogas purification system used a multi-stage scrubber setup instead of a standard filter to treat raw biogas from the septic tank. It consisted of three transparent 254 mm water filter housings, modified and sealed with 15 mm connectors for airtight operation. Each chamber included fittings that transitioned from 25 mm PVC to 8 mm pipes, connected to a clear PVC hose for visible gas flow. Identical configurations were used across all stages to ensure uniform performance. Different filtering media were used in each stage to effectively remove impurities like hydrogen sulfide, moisture, and particulates, improving overall purification efficiency.

D. Biogas Collection System

A sealed collection system was set up to direct biogas from the septic tank vent to the filtration unit. As illustrated in Figure 1, the system used a 40 mm PVC pipe capped at the top, with a 15 mm hole to fit a biogas outlet. A 15 mm elbow fitting was inserted into the hole and connected to a 150 mm section of 15 mm PVC pipe. This pipe led to a 15 mm tee fitting, which then connected via another 150 mm pipe to the filtration system's inlet.

Figure 1. Biogas Collection Setup

Following purification, the biogas passed through a monitoring section equipped with sensors to evaluate its quality. A 15 mm PVC ball valve was installed before the storage unit to control gas flow and allow safe detachment of the storage container. The gas was then transferred through a 300 mm PVC pipe into a tire inner tube, used as a cost-effective and flexible storage option. To check for leaks, the system was pressurized with air and tested using soapy water—bubbles indicated leaks, while none confirmed a sealed system. This provided a safe and reliable way to verify system integrity before using real biogas.

E. Biogas Monitoring and Testing

Biogas production from the retrofitted septic tanks was monitored over 10 days, focusing on methane levels, temperature, and flow rate. Sensors were placed before and after the filtration unit to track changes in gas quality. Data was collected three times daily—at 7:00 AM, 12:00 PM, and 7:00 PM—coinciding with the researcher's availability and capturing temperature-related variations that impact biogas output. At each interval, methane concentration, temperature, and flow rate were measured at both points. This method provided a well-rounded view of system performance throughout the day. All readings were recorded and analyzed to evaluate the effectiveness of biogas collection and purification.

F. Biogas Utilization Testing

To assess its suitability as a household fuel, biogas collected over 10 days was tested using a biogas stove. The evaluation focused on flame quality, heat distribution, and combustion time. In the test, 300 mL of water was heated in a heat-resistant container, and the time to reach boiling (100°C) was recorded as a measure of efficiency. A thermometer tracked temperature changes, and flame color and stability were observed, with adjustments made for optimal burning. Due to limited gas supply, only one test was conducted, offering preliminary insights into the biogas's performance.

III. RESULTS AND DISCUSSION

A comprehensive structural and functional evaluation was conducted on the existing septic tank prior to its retrofitting for biogas recovery. The tank is a single-chamber unit made of reinforced concrete, measuring approximately 1.37 m wide, 2.13 m long, and 1.83 m deep, and has been operational for about ten years. It is located directly beneath a comfort room, which serves as its only source of wastewater and organic material. Visual inspection confirmed that the tank is in good structural condition, with no signs of cracks, spalling, or deformation.

TABLE 1. Results of the Structural and Functional Assessment Before Retrofitting the Existing Septic Tank

Criteria	NPCP Standard	Assessed Septic Tank Specification	Compliant?
Liquid Capacity	Minimum 1.2 cubic meters for single-family dwellings	~5.35 cubic meters	Yes
Construction Material	Watertight, durable materials (e.g., reinforced concrete)	Reinforced concrete with solid base	Yes
Structural Condition	No cracks, spalling, deformation	No visible structural damage	Yes
Inlet and Outlet Piping	Must ensure proper flow and detention time	In good condition, no leaks or dislocations observed	Yes
Compartment Design	Minimum of 2 compartments (as per Section 1003.3 of the NPCP)	Single compartment only	No
Elevation Above Ground Level	Should prevent surface water infiltration; allow easy maintenance access	0.70 meters above ground; prevents waterlogging	Yes
Manhole Access (Section 1003.1)	Must provide access for inspection/maintenance	Present and structurally sound	Yes
Manhole Size (Section 1003.2)	Minimum 508 mm (0.508 m)	300 mm x 300 mm	Partially
Cleanout Access	Required for mechanical cleaning	Present and functional	Yes

According to the Revised National Plumbing Code of the Philippines (NPCP, 2015), septic tanks for single-family homes must have a minimum liquid capacity of 1.2 m³ and be constructed from watertight, durable materials. The evaluated tank meets and exceeds these standards with an estimated volume of 5.35 m³ and reinforced concrete construction, confirming its suitability for biogas retrofitting.

Hydraulic components like inlet and outlet pipes were found to be intact and leak-free, ensuring effective wastewater flow and retention. Minor dampness was observed on the external wall, likely due to environmental humidity, but no pooling or structural damage was found.

The tank's elevation—0.70 meters above ground—supports proper drainage, minimizes waterlogging, and enhances maintenance access, aligning with code requirements for environmental protection and system maintenance.

Access points include a 0.30 m × 0.30 m manhole and a cleanout, both in good condition. While functional, the manhole does not meet the NPCP's required minimum dimension of 0.508 m, indicating that an upgrade may be needed for full compliance and easier maintenance.

After evaluating the septic tank, the vent pipe was identified as a key component for biogas retrofitting. As shown in Figure 2, modifications included adding an elbow joint and a vertical extension to create a clear, efficient pathway for gas release from the digestion chamber to the collection system.

Figure 2. Modification of the Septic Tank's Vent Pipe for Biogas Collection

Post-retrofitting, the vent pipe now serves two main functions: safely capturing biogas and preventing gas buildup inside the tank. As illustrated in Figure 3, a network of 32 mm (1¼ inch) PVC pipes, along with a 90-degree elbow joint, was installed to direct gas flow efficiently, reduce turbulence, and minimize condensation or blockage risks. The vent pipe extends about 1 meter above the tank, allowing passive gas release and supporting steady, low-pressure biogas flow (0.01–0.03 MPa) to the storage unit.

A critical addition to the system is a multi-stage gas scrubber made from three repurposed water filter housings, which remove moisture, CO_2, and hydrogen sulfide, improving biogas quality for combustion. An Arduino-based monitoring system with sensors tracks gas flow, methane levels, temperature, and pressure in real time, enabling performance optimization.

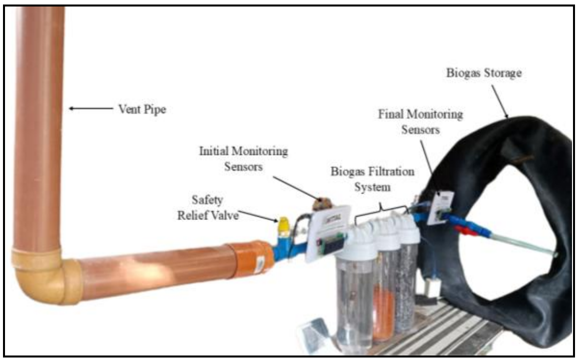

Figure 3. Biogas Collection Setup

To ensure the system is airtight, it was pressurized with an air pump, and a soapy water test was performed to detect and fix leaks. At the end of the system, a recycled tire inner tube was used as a flexible, cost-effective storage unit, allowing temporary gas storage and energy availability during production fluctuations.

Figure 4 presents temperature data recorded over a 10-day period at 7:00 AM, 12:00 PM, and 7:00 PM, offering insights into how ambient temperature affects biogas production in a retrofitted septic tank.

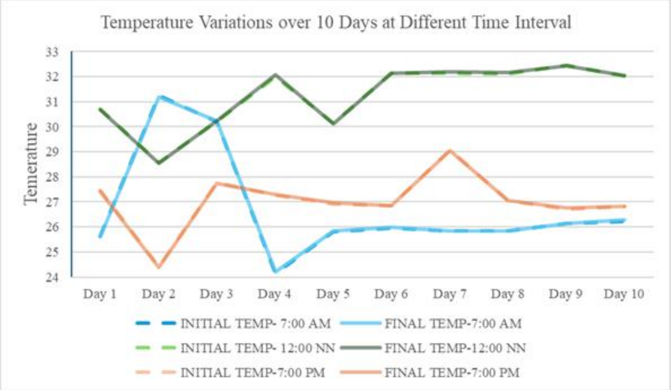

Figure 4. Temperature Variations Over a 10-day Monitoring Period at Three Daily Intervals: 7:00 AM, 12:00 PM, and 7:00 PM

Midday temperatures were consistently the highest, often exceeding 32°C—an optimal range for mesophilic anaerobic digestion (25–35°C), which enhances microbial activity and boosts biogas generation (Wang et al., 2025). In contrast, the lowest temperatures occurred at 7:00 AM, ranging from 24°C to 26°C. While not reflective of internal digester temperature, these cooler morning readings suggest reduced gas pressure and flow due to thermal contraction, which may affect biogas volume and movement (Zhang et al., 2023).

Overall, the data showed only minor temperature variations throughout the day, indicating a relatively stable thermal environment—crucial for maintaining microbial balance and consistent biogas output (Ekong et al., 2025). Notably, elevated evening temperatures on Days 6 and 7 suggest some passive heat retention, which could be enhanced further through insulation or greenhouse-style coverings (Ma et al., 2024).

Figure 5 presents biogas flow rates measured over a 10-day period at three daily intervals: 7:00 AM, 12:00 PM, and 7:00 PM. The data shows a clear daily pattern, with the highest flow rates consistently recorded at noon.

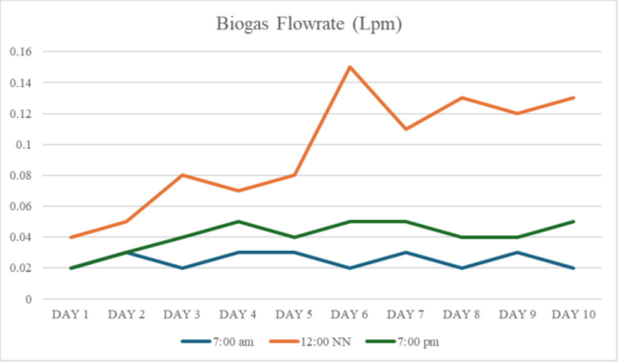

Figure 5. Biogas Flow Rate Over a 10-Day Monitoring Period

The peak flow rate occurred on Day 6 at 12:00 PM, reaching 0.15 liters per minute (Lpm). This midday increase is likely due to higher ambient temperatures, which may raise gas pressure and enhance flow through the collection system. Although sensors were placed outside the digester, warmer surroundings likely influenced gas dynamics, supporting findings by Khan et al. (2021).

Morning readings (7:00 AM) were the lowest, typically under 0.03 Lpm, likely due to cooler temperatures that reduce gas pressure and flow (Mekonnen et al., 2022). Evening values (7:00 PM) were moderate, ranging from 0.03 to 0.05 Lpm, with less fluctuation than at midday.

Overall, the biogas flow rate increased over time, with early days (Day 1–3) showing lower outputs and later days (Day 6–10) demonstrating more stable and improved performance. This upward trend indicates enhanced system efficiency, likely due to sustained anaerobic digestion and better gas capture—similar to outcomes reported in other retrofitted systems (Singh et al., 2020).

Figure 6 illustrates the changes in post-filtration methane concentration over a 10-day monitoring period, with measurements taken three times daily—at 7:00 AM, 12:00 PM, and 7:00 PM. The results show clear daily fluctuations that could impact both the efficiency of biogas use and potential methane emissions.

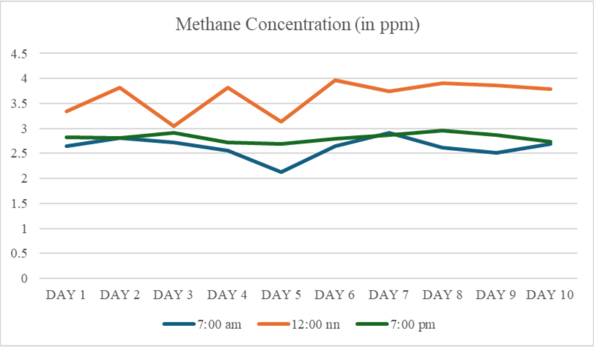

Figure 6. Time-Based Changes in Post-Filtration Methane Concentration from Biogas Generated by Retrofitted Septic Tank: A 10-Day Monitoring Assessment

Methane levels peaked consistently at noon, ranging from about 3.1 to 4.0 ppm, with the highest value observed on Day 6. While ambient temperatures were not recorded, the increased midday methane concentrations are likely linked to higher internal temperatures in the biogas pipes, where the sensors were located. These conditions may reflect enhanced microbial activity during warmer periods, leading to greater methane production, as noted by Huynh et al. (2021).

In contrast, the lowest methane concentrations occurred in the early mornings, particularly on Day 5, at around 2.0 ppm, possibly due to reduced gas buildup and slower flow in cooler conditions. Evening measurements remained relatively stable, ranging from 2.7 to 2.9 ppm, indicating steady output during this time.

The presence of methane even after filtration, especially during peak periods, suggests some inefficiencies in the gas cleaning process. As Huynh et al. (2021) explained, methane variation can also be influenced by factors like chemical oxygen demand (COD) and oxidation-reduction potential (ORP) within the septic tank. These findings highlight the need to enhance filtration performance and implement better emission control measures in retrofitted systems.

The relationship between biogas flow rate and methane concentration was analyzed using a scatter plot and Pearson correlation. As shown in Figure 7, the data revealed a clear positive trend, with a strong correlation coefficient of r = 0.8471, p < .00001, indicating a statistically significant connection. This means that higher methane concentrations are consistently associated with increased biogas flow rates.

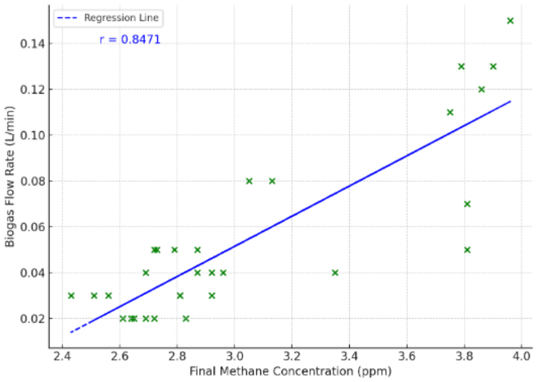

Figure 7. A Scatter Plot Shows the Relationship Between the Final Methane Concentration and the Biogas Flow Rate.

These findings are consistent with existing research, such as Duguma (2024), who reported high methane yields under optimal conditions, and Sawettabut et al. (2023), who showed improvements through co-digestion strategies. Obileke et al. (2024) also highlighted the importance of operational optimization in boosting methane output.

In this study, biogas was collected using a cost-effective method by modifying the septic tank's vent pipe—without altering the tank's internal structure. The strong correlation between flow rate and methane concentration suggests that even simple retrofitting techniques can significantly improve energy recovery from older septic systems.

One of the study’s main goals was to evaluate whether biogas from a retrofitted septic tank could be used for energy purposes, particularly heating. A key indicator of biogas quality was the pale blue flame observed during combustion, which signifies efficient burning and a high methane content—confirming data from the methane sensors. This aligns with previous findings showing that biogas with over 50% methane typically produces a clean blue flame suitable for energy use (Karki et al., 2022).

To test its practical energy potential, a single combustion experiment was performed by heating 300 mL of water. The water reached boiling in just 1 minute and 33 seconds, demonstrating the biogas' strong calorific value and potential for household applications like cooking or water heating. Due to limited gas availability from the 10-day collection period, only one trial was conducted.

The observed performance aligns with benchmarks showing that methane-rich biogas can reach flame temperatures between 870°C and 1,000°C, depending on burner efficiency and air-to-fuel ratio (Liu et al., 2022). Despite limited testing, results confirm the technical feasibility of using biogas from retrofitted septic tanks for small-scale energy needs, supporting previous studies that highlight its viability for domestic heating and cooking (Sanata et al., 2023).

IV. CONCLUSION

This study demonstrated the technical feasibility and energy potential of retrofitting a 10-year-old septic tank for biogas production. The research focused on assessing the structural suitability of the tank, implementing a low-cost biogas recovery system, and analyzing key operational parameters such as gas flow rate, volume, methane concentration, and temperature variations.

The initial qualitative and structural assessment confirmed that the septic tank was in good condition and met essential criteria outlined in the Revised National Plumbing Code of the Philippines (2015). Despite its age, the tank exhibited no signs of structural compromise, making it a viable candidate for retrofitting. Integrating a modified vent pipe system, gas conveyance lines, and a simple gas purification setup—combined with real-time sensor monitoring—allowed the tank to operate effectively as a decentralized biogas recovery system without requiring significant redesign.

Over the 10-day monitoring period, the system exhibited a progressive increase in biogas flow rate and volume. Daily production rose from 43.2 liters on Day 1 to a peak of 100.8 liters on Day 6, with flow rates consistently highest at midday, reaching up to 0.15 L/min. This diurnal pattern aligned with ambient temperature fluctuations, which significantly impacted gas pressure and flow behavior. Statistical analyses confirmed a strong positive correlation between methane concentration and biogas flow rate ($r = 0.8471$, $p < .00001$), highlighting the interconnected effects of operational and environmental variables on system performance.

The filtration system improved methane concentrations, increasing them from initial values of 1.13–1.81 ppm to post-filtration values of 2.43–3.96 ppm. A combustion test validated the quality of the produced biogas, as indicated by a pale blue flame and rapid water boiling, confirming its suitability for small-scale heating applications.

In summary, retrofitting a long-used septic tank using low-cost components and passive design principles offers a viable pathway for biogas recovery and utilization. The results affirm that with minimal intervention, existing septic infrastructure can be repurposed to support renewable energy generation, particularly in rural or off-grid communities. This approach enhances the sustainability of wastewater management systems and contributes to energy resilience in underserved areas.

REFERENCES

[1] Duguma, Abu; Bekele, Tadele; Geda, Abera. (2024).Biogas Production through Anaerobic Codigestion of Distillery Wastewater Sludge and Disposable Spent Yeast. International Journal of Chemical Engineering. Retrieved

[2] Ekong, Emmanuel; Owolabi, Adewale; Akintoye, Michael. (2025).Socioeconomic impact assessment of bio-digester septic tank adoption on biogas availability in communities. International Journal of Engineering and Modern Technology, 11(1), 66–77.

[3] Huynh, Loi, Tan., Hidenori, Harada., Shigeo, Fujii., Lien, Pham, Hong, Nguyen., T., H., Hoang., Hai, Trung, Huynh. (2021). 1. Greenhouse Gas Emissions from Blackwater Septic Systems. Environmental Science & Technology, doi: 10.1021/ACS.EST.0C03418

[4] Karki, Amrit Bahadur, Shrestha, Jagan Nath, & Bajgain, Sundar. (2022). Biogas as renewable source of energy in Nepal: Theory and development. Alternative Energy Promotion Centre. Retrieved March 19, 2025, from https://doi.org/10.13140/RG.2.2.34560.17921

[5] Liu, Aiguo., Fan, Ruiyang., Liu, Qiaochu., Xi, Lei., & Zeng, Wen. (2022). Numerical and Experimental Study on Combustion Characteristics of Micro-Gas Turbine Biogas Combustor. Energies, 15(21), 8302. Retrieved January 26, 2025, from https://doi.org/10.3390/en15218302.

[6] Ma, Feng, Zhang, Yan, & Liu, Xiaoming. (2024). Thermal insulation effects on anaerobic digestion performance in rural septic systems. Renewable Energy Systems Journal, 19(2), 45–59.

[7] Mekonnen, Ephrem Hailu., Gebresenbet, Girma., & Bernes, Göran. (2022). Diurnal variations in biogas yield and microbial response under ambient conditions. Biomass and Bioenergy, 161, 106482. Retrieved March 18, 2025, from https://doi.org/10.1016/j.biombioe.2022.106482.

[8] Obileke, KeChrist., Makaka, Golden., & Tangwe, Stephen. (2024). Improvement of biogas yields in an anaerobic digestion process via optimization technique. Environment, Development and Sustainability. Retrieved January 30, 2025, from https://doi.org/10.1007/s10668-024-04540-6

[9] Sanata, Andi., Sholahuddin, Imam., Rosyadi, Ahmad Adib., Nanlohy, Hendry Y., Nashrullah, Muhammad Dimyati., Erawan, Ilyas Nugraha Budi., Mulyadi, Santoso., Ramadhan, Mochamad E., (2023). Characterization of Biogas as an Alternative Fuel in Micro-Scale Combustion Technology. International Journal of Integrated Engineering, 15(4), 64–76..

[10] Sawettabut, Nattapon., Sungthong, Daoroong., Ratasuk, Nopawan., & Santisukkasaem, Umarat. (2023). Biochemical Methane Potential and Kinetics on Anaerobic Co-digestion of Food Waste and Cellulose-based Food Packaging Product. The Journal of Industrial Technology. Retrieved January 28, 2025, from https://doi.org/10.14416/j.ind.tech.2023.11.001

[11] Singh, Amritpal., Pant, Deepak., & Korres, Nicholas. (2020). Biogas generation from anaerobic digestion of retrofitted domestic wastewater systems. Journal of Environmental Management, 255, 109846. Retrieved January 29, 2025, from https://doi.org/10.1016/j.jenvman.2019.109846

[12] Wang, Shuai., Ma, Wei., Zhao, Guang., & Lu, Xiaofei. (2025). Influence of temperature on biogas production efficiency and microbial community in a two-phase anaerobic digestion system. Science of the Total Environment, 857, 159–168.