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Biomass Gasifier Stove with Digester and Integrated Pressure Gauge

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ABSTRACT

This research focuses on the development of a biogas digester with an integrated stove, designed to offer a sustainable alternative to the rising costs of liquefied petroleum gas (LPG). By utilizing the co-digestion of agricultural, animal, and food wastes, the system enhances methane yield, making it more efficient for biogas production. Key safety features, including a pressure gauge and external storage, were integrated into the digester design. Over a six-week testing period, the system produced enough biogas to provide 37 minutes of cooking time. The digester demonstrated a performance difference of 12.57% compared to a standard 2.7-kg commercial LPG cylinder, proving its viability as a cost-effective and renewable fuel source. This innovation supports the broader adoption of renewable energy and presents a practical solution for reducing dependence on conventional fossil fuels.

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INTRODUCTION

This study developed a biogas digester with enhanced safety, storage, and monitoring capabilities for efficient biogas production. Specifically, it sought to determine the optimal amount of biowaste required, assess the biogas yield over two-week intervals, evaluate the cooking duration on a low stove setting, and perform a cost comparison with a 2.7-kg commercial gas cylinder. By achieving these objectives, the research contributed to the development of safer, more efficient biogas digesters and promoted the use of sustainable energy solutions.

Biogas is a renewable energy source with no negative environmental impact, produced through the anaerobic digestion of biodegradable materials such as agricultural, animal, and food wastes . This process occurs in reactors of various sizes and forms, depending on site and feedstock conditions, and involves complex microbial communities breaking down the waste to generate biogas. In the Philippines, the Department of Agriculture (DA) advocates for biogas production due to the abundant biowaste resources available.

Typical digester designs consist of a sealed container, slurry outlet, and biowaste inlet. However, a prevalent danger is the release of harmful gases or explosions due to high-pressure build-up. Preventative measures include using non-sparking tools, explosion-proof electrical services, and monitoring devices to control pressure. Additionally, smoking and open flames near digesters are strictly prohibited.

This study introduces co-digestion, which involves combining different biowastes, as a method for faster and higher methane yield biogas production, surpassing the minimal output from mono-digestion of fruit and vegetable peels. Examples of co-digestion include mixing cow dung with sewage sludge and kitchen wastes with poultry manure. As inflation drives fuel prices higher, biogas presents a cheaper, safer, and environmentally friendly alternative to liquefied petroleum gas (LPG). The proposed biogas digester will feature integrated safety components, such as a pressure gauge, external storage, and a recycled tire interior to increase gas production capacity. Additionally, the digester will be connected to a stove, providing a practical alternative for cooking fuel

LITERATURE REVIEW

Methane gas production in kitchen garbage is studied through research. The study conducted surveys and categorized and characterized kitchen trash from multiple kitchens and canteens in order to assess the possibility for producing biogas. The garbage produced has a daily biogas production capacity of 600 m3. Next, using 30 KVA and 50 KVA generators, the biogas is cleaned and processed to produce power. The electricity generated serves as a backup source for the campus girl's hostel's lighting load (Muthu et al., 2017).

As the world's population grows, food waste and hoarding have become significant global challenges. The exponential rise in food waste is a major worry for modern society because it leads to pollution, health issues, and a shortage of disposal options. Implementing the right measures to reduce food waste is crucial when using standard management strategies. Today, research is being done to better society by exploring different methods of processing and handling food waste. In order to cut down on food waste, energy use, and manufacturing, anaerobic fermentation has become one of the most environmentally beneficial and promising methods. Numerous facets of anaerobic food biodegradation systems were investigated, such as ambient factors, microbial population ratios, co-substrate effects, and computational tools that are accessible for food treatment research (Paritosh et al., 2017).

The population of the globe is predicted to grow quickly, reaching nine billion people by the year 2050. Wood, sawdust, straw, manure, rubbish, municipal waste, sewage, and other elements can all be found in biomass, a renewable resource. In addition to helping the research community comprehend the current state of affairs, potential future directions, and the circumstances in each country, this study looked at the status and trends of the field's research. Scientific research indicates that the US is leading the way in the study of biomass as a renewable energy source, with China, India, Germany, and Italy following suit. The National Institute of Renewable Energy, Danmarks Tekniske Universitet, the Chinese Ministry of Education, and the Chinese Academy of Sciences are the next most active academic institutions in the field. Two of the six groups or groupings were linked to the production of liquid fuels from biomass. Perea-Moreno et al. (2019) discovered eight clusters that discussed his three countries of origin.

The primary material for making pellets was coffee husks, while the binder was a mixture of molasses and tapioca flour. The greatest outcome was obtained with 10% tapioca flour added. Pellets had the following characteristics: density: 610 kg/m3, moisture: 8.03%, volatile: 81.79%, mixed carbon: 15.18%, calorific value: 17.55 MJ/kg, water boiling time: 10 minutes, fuel consumption: 0.008 kg. Bottom. /min. According to Hannono et al. (2022) the furnace's average thermal efficiency was 3.25 ppm.

The most important energy source on Earth, biomass is utilized for small-scale production, heating, and cooking. It contributes 10–14% of global energy and has the potential to provide 30–40%. It is a crucial part of all energy projections. This overview looks at the potential and application of biomass energy, liquid biofuels for transportation, the impact of changing land use, the debate over fuel vs food, sustainability and environmental issues, subsidies, energy balance, and global biomass energy trade. It also examines the underlying flaws and issues that affect biomass energy, such as the conflict between food and biofuels, soil erosion, and a lack of scientific evidence (Rosillo-Calle, 2016).

Composting waste is a global practice to lower the amount of waste that ends up in landfills. The sort and chemical composition of the combined biomass, however, receives less attention. Studies on composting were carried out to find out if the maturity or quality of compost is affected by the raw materials (chemical composition, blends, and ratios) or by the conditions and duration of the composting process. After 120 days, the maturity, stability, and quality of the products made under the same composting conditions and times were evaluated using physical, chemical, and biological methods on four composts. According to Muscolo et al. (2018), compost generated from residual green plant material was richer in nutrients and phenols, and it had the highest and best quality CSC index. In contrast, the olive Polex composite had the highest mature T-score and organic matter loss.

The impact of particle size on the biochemical transformation of plantain peels was investigated. The raw material was processed to three unique average particle sizes (0.5, 1.0, and 1.5 mm) using a 1.5 kW single-stage laboratory milling machine. Banana peels that had not been handled or prepped were mesophilically digested anaerobically for 30 days in four batch reactors. Pretreated raw material medium size (0.5, 1.0, 1.5 mm) and raw sample showed increases in cumulative biogas production of 54.05, 36.22, and 27.02% above raw material, respectively. Since the power required for pretreatment is cheap, it is likely possible to mechanically pretreat cooked banana peels to the average particle size under investigation (UDEH et al., 2022).

The anaerobic digestion of organic materials produces biogas, which is a sustainable energy source containing methane, carbon dioxide, and other trace chemicals. In order to meet its goals for reducing greenhouse gas emissions, California is expanding its infrastructure for the generation of biogas. The findings indicated that whereas food waste biogas had a notable concentration of compounds including sulfur, MSW biogas had a high concentration of chemicals associated with volatile chemicals. Dairy manure-derived biogas had trace amounts of certain compounds, while combustion products displayed somewhat more substantial hazardous effects. The toxicity of biogas flue gas was not affected by atmospheric aging (Li et al., 2019).

We demonstrate in this work a 100 kW flexible vortex combustor with an adiabatic chamber that can burn waste biogas with an unstable composition. Waste biogas containing 5–30 vol% CH4 in CO2 was burned in the presence of air, an O2-enriched environment, or hydrogen addition to study the main combustion features and chemiluminescence emission spectra. Although O2-enriched environments increased NOx emissions during combustion, the flexibility of the burner to operate in such conditions produced superior results. The spectral intensity ratio of OH* and CH* and the CH4 content in CO2 under different H2 or O2 enrichments have a linear relationship that predicts the vent limit in waste biogas combustion (Striōgas et al., 2020).

The process of digesting animal feces via anaerobic digestion (AD) yields useable solids and flammable gas, or "biogas". Moreover to producing power and gas for heating, biogas may run generators and motors. Biogas could prove to be a financially viable renewable energy source for agricultural enterprises as the prices of natural gas and electricity continue to rise. The Anaerobic Digestion: Biogas Utilization and Cleanup fact sheet (Oklahoma State University, 2017) discusses cleaning or treating AD biogas prior to use.

Leachate from the Bagendung Cilegon landfill, goat dung, and cow dung were among the starters used to study the characteristics of biogas flames produced during the treatment of organic waste. Tests on various types of biogas showed that flame heights in biodigesters with leachate starters were the lowest. However, the highest flame heights are found in fermentations that use cow dung as a starter. Relative to biogas created with cow dung as a starter, the ideal flame temperature of biogas generated with leachate starting is 1027°C, which is 7% lower. Cow dung was demonstrated to be the best starter when contrasted with goat feces and leachate. But in the biodigester process, it is not optimal to start with leachate when producing biogas. Everything went really well.

METHODOLOGY

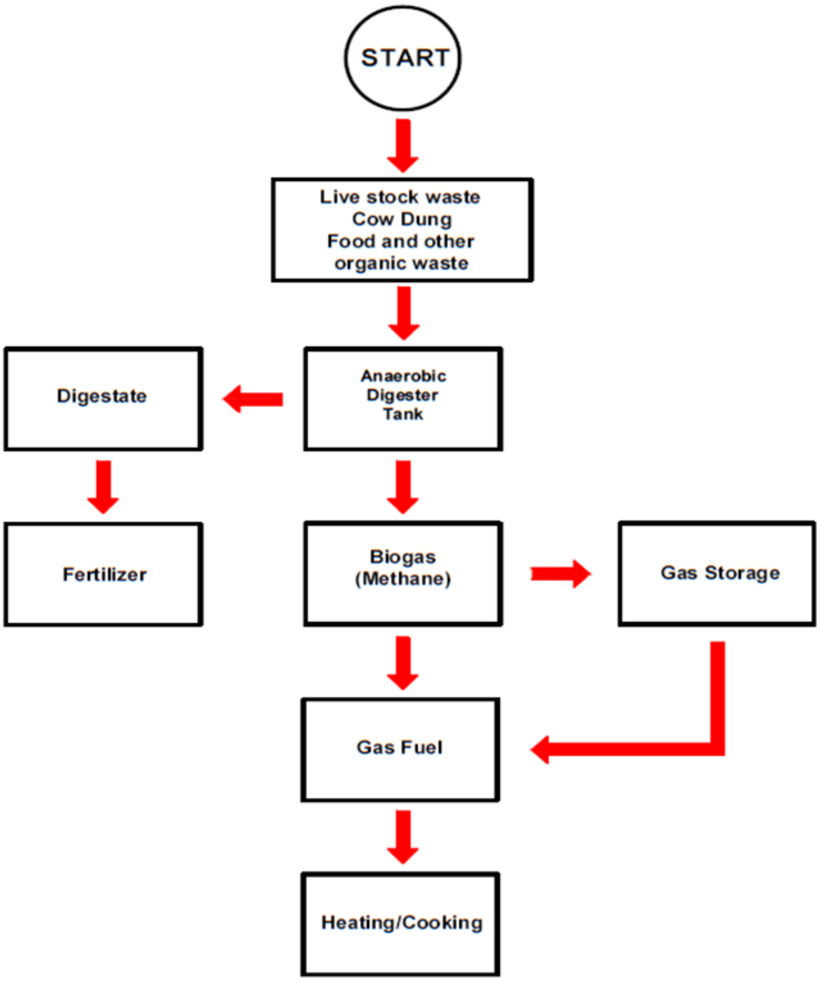

Figure 1. Flow Chart of the System

Figure 1 displays the system flow chart. The biowastes that are integrated ought to yield gasoline-like fuel. Following a three-week fermentation period, the digester should generate biogas every two weeks. Following production, the biogas is sent to gas storage to make place for more biogas to be created, or it can be used straight for cooking and heating. At any point, gas production and storage can be disconnected and used separately. Fertilizer can be made from the digestate residue that settles to the bottom of the digester tank in the form of mud. Fuel can then be made from the gas that is created.

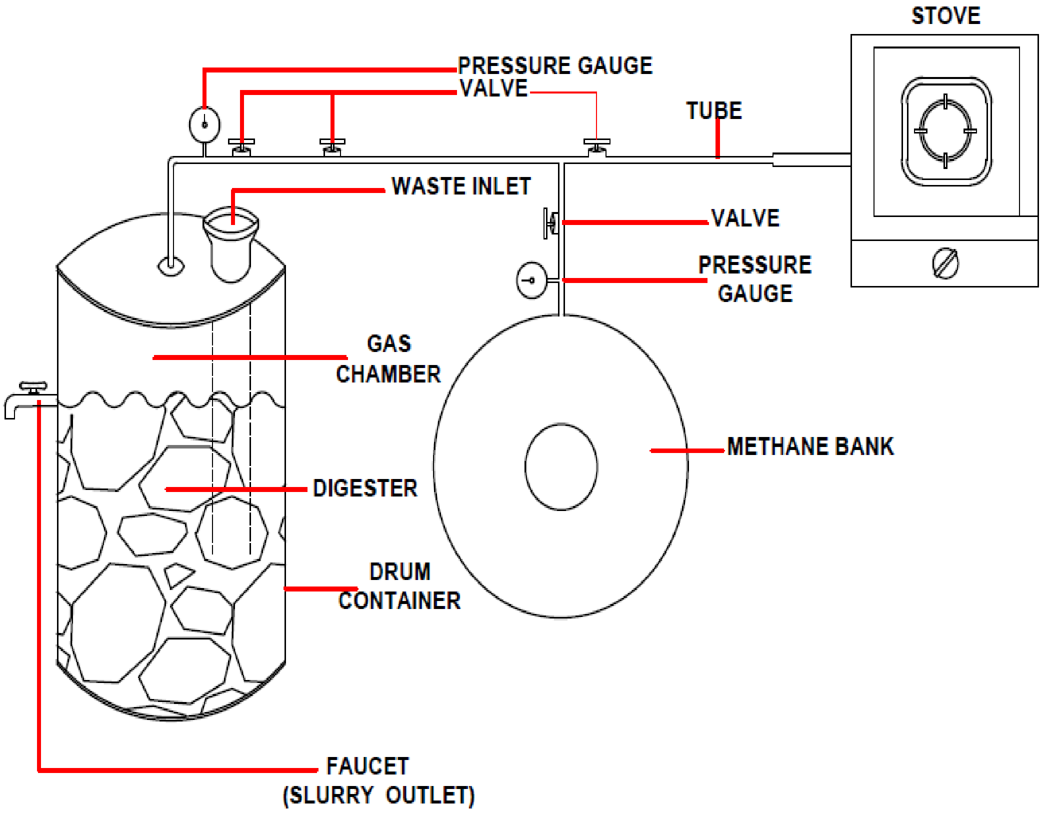

Figure 2. Actual Design of the System

The system's real architecture is depicted in Figure 2. The anaerobic digestion process produced methane gas, which was used to fuel the stove. The digester consisted of a hermetically sealed 160-liter drum. An atmosphere that permits oxygen-free biomass fermentation is created by a biogas digester. Adding biomass—such as manure, organic waste, or sewage effluent—to large tanks is often how this is done. To optimize biogas production, we combined three distinct biowastes in this system: vegetables, fruit and vegetable peels, and carabao dung, an anaerobic digestion stimulant. The tanks are sealed against air and the slurry is mixed.

Biowaste Composition

Carabao dung is used by the system as an anaerobic digestion stimulant. Twenty-five liters of water and carabao dung are put into the digester. Fruit, vegetable peels, and vegetables make up the biowaste composition inside the digester. The overall weight of the solid biowaste content is 14 kg.

Tested Objects

To create gasolete and biogas, the water must be boiled for two weeks. The biogas generated during a two-week period was cooked.

Sample Collection

The stove is used to fire the generated biogas, and the amount of time that passes between ignition and the biogas storage running out of gas is recorded. 250 mL of water is brought to a boil using the gasolete, and the time is noted. Biogas is processed in the same way.

Statistical Tool

The heat generated by the biogas is compared to the heat produced by the commercial gas in order to calculate the percentage difference in heat production. Commercial gas and biogas heat capacities are calculated using the heat capacity formula (1). The required parameters and formula are indicated below in determining the percentage difference (2).

$$Q = mC\Delta T \qquad (1)$$

Q = Heat Energy
m = mass
C = specific heat capacity = $\frac{1\ cal}{g{\cdot}°C}$
ΔT = change in temperature

$$Percentage\ Difference = \frac{Pc-Pb}{\frac{(Pc+Pb)}{2}} \text{ x } 100 \qquad (2)$$

Pc = Power Generated by Commercial Gas
Pb = Power Generated by Biogas

Whereas, any percentage that yields between 8% and 54% for electricity generation; 16% and 83% for heat; 18% and 90% for electricity and heat (Hakawati et al., 2017). Lower the percentage provided is deemed inefficient and higher is deemed very efficient.

Specific Heat Capacity

Commercial Gas	Biogas
m = 250 mL = 250 g **T1 = 33.3°C** **T2 = 100°C** **Time to boil = 3:17 Minutes** **=** $\frac{.17}{60}\ x\ 100$ **= 0.28 minute** **Total time: 3.28 minutes**	m = 250 mL = 250 g T1 = 33.3°C T2 = 100°C Time to boil = 3:43 Minutes = $\frac{.43}{60}\ x\ 100$ = 0.72 minute Total time: 3.72 minutes

Specific Heat (Q) = $mC\Delta T$

$$Q = (250\text{mL})\ (\frac{1cal}{g{\cdot}°C})\ (100°C - 33.3°C)\ (\frac{4.186J}{1cal})$$

Q = 69801.55J

Power = $\frac{J}{sec} = Watts$	**Power =** $\frac{J}{sec} = Watts$
Pc = $\frac{69801.55J}{3.28x\frac{60\,sec}{1\,min}} = 354.68\,Watts$	**Pb =** $\frac{69801.55J}{3.72x\frac{60\,sec}{1\,min}} = 312.73Watts$

Percentage Difference

$$Percentage\ Difference = \frac{Pc - Pb}{\frac{(Pc + Pb)}{2}} \times 100$$

$$Percentage\ Difference = \frac{354.68W - 312.73W}{\frac{(354.68W312.73W)}{2}} \times 100$$

Percentage Difference = 12.57%

RESULT AND DISCUSSION

Determining the Amount of Biowaste Needed to Produce Biogas in Three Trails

Table 1. Biowastes needed for biogas production

Week	Biowastes	Biogas (Kg/cm^2)
Trial1	5 Kgs	0.2
Trial 2	4 Kgs	0.23
Trial 3	5 Kgs	0.27

The following biogas production rates were achieved during the first two weeks of the experiment: 5 kg of biowastes produced 0.2 kg/cm2 of biogas, 4 kilogram of biowastes produced 0.23 kg/cm2 of biogas, and 5 kg of biowaste produced 0.27 kg/cm2 of biogas. The buildup of biowastes inside the digester is causing an increase in the production of biogas. The amount of biowastes in the digester directly relates to the amount of biogas produced. The digester generated the least amount of biogas during the initial weeks of anaerobic digestion and increased over time as the biowastes were subjected to an extended anaerobic digestion process. This results from the addition of biowastes gradually every two weeks. The bacteria can continue their anaerobic digestion by using the biowastes as a food supply. Biogas output is impacted by the lengthier time and higher volume of biowastes.

Table 2. Cooking Hours lapsed using the produced biogas

Week	**Stove Setting**	**Cooking Time**
1 – 2 Weeks	Low	10.57 Minutes
3 – 4 Weeks	Low	12.16 Minutes

5 – 6 Weeks	Low	14.27 Minutes

In the first two weeks, the biogas produced made a fire for 10.57 minutes in a low stove setting. The second trial managed recorded 12.16 minutes. Lastly, the third trial recorded 14.27 minutes. The biogas produced is directly proportional to the time a stove can cook.

Cost of the Biogas Produced Compared to Gasolete

Table 3. Cost per biogas produced in 6 weeks

Storage	**Biogas Produced**	**Cost**
1 – 2 Weeks	0.2 Kg/Cm^2	Php 18.89
3 – 4 Weeks	0.23 Kg/Cm^2	Php 40.61
5 – 6 Weeks	0.27 Kg/Cm^2	Php 66.11

The price of the generated biogas is contrasted with that of a 2.7-kg fuel tank. The equivalent of 0.2 kg/cm2 is equivalent to PHP 18.89 for a commercial gasolette. Weeks that follow are equivalent to PHP 40.61, and the total amount of biogas generated is equivalent to PHP 66.11 in commercial gas.

CONCLUSIONS AND RECOMMENDATIONS

The biogas digester successfully produced biogas capable of serving as an alternative fuel source. This one-time investment system becomes more cost-effective with continued usage, demonstrating a total cooking time of 37 minutes over six weeks. The addition of biogas storage proved beneficial, allowing for an extended period of biogas production. The system's overall efficiency was measured at 88.41% compared to a 2.7-kg commercial gas cylinder, with the production valued at PHP 66.11 worth of commercial gas.

To enhance the system's efficiency and effectiveness, the researchers recommend developing a larger digester system and extending the testing periods. Additionally, it is essential to determine the amount of biogas produced before the system requires maintenance. Further exploration into the bio waste combinations could yield more scientific insights, particularly in assessing the slurry's effectiveness as a fertilizer for plants.

ADVANCED RESEARCH

Despite the promising results, this study has certain limitations that warrant further investigation. One significant limitation is the scale of the digester system, which could benefit from increased capacity for higher biogas yields. Future research should focus on larger systems and longer testing durations to better understand the long-term viability and maintenance needs.

Further research suggestions include optimizing bio waste combinations to enhance biogas production efficiency and investigating the slurry's potential as an effective fertilizer. Additionally, exploring more scientific approaches to bio waste processing and its impact on biogas and slurry quality could provide valuable insights for improving the system's overall performance. These advancements could significantly contribute to the broader adoption and development of sustainable biogas technologies.

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REFERENCES

Hnain, Cockburn, & Lefebvre (2011). Microbiological processes for waste conversion to bioenergy products: Approaches and directions. Jstor, 19, 214–237.

Mat Saad, N. F., Mamin, N. N., Md Zain, S., Ahmad Basri, N. E., & Md Zaini, N. S. (2013). Composting of Mixed Yard and Food Wastes with Effective Microbes. Jurnal Teknologi, 65(2). https://doi.org/10.11113/jt.v65.2196

Rosillo-Calle, F. (2016). A review of biomass energy , shortcomings and concerns. *Journal of Chemical Technology & Biotechnology, 91(7), 1933–1945.* https://doi.org/10.1002/jctb.4918

Muscolo, Papalia, Settineri, Mallamaci, & Jeske. (2018). Comparison of obtained composts on soil properties. *Journal of Cleaner Production, 195, 93–101.* https://doi.org/10.1016/j.jclepro.2018.05.204

Vassilev, Vassileva, & Vassilev. (2015). Advantages and disadvantages of composition and properties of biomass in comparison with coal: An overview. Fuel, 158, 330–350. https://doi.org/10.1016/j.fuel.2015.05.050

UDEH, N. E., Ozioko, E. R., & Njoku, H. (2022). Biogas Production from Cooking Banana Peel: Effect of Substrate Particle Size on Biogas Yield and on Bio-Kinetics Parameters. *SSRN Electronic Journal.* https://doi.org/10.2139/ssrn.4078695

Li, Alaimo, Kim, Kado, Peppers, & Xue. (2019) . Composition and Toxicity of Biogas Produced from Different Feedstocks in California. Pub Med Central. https://doi.org/10.1021/acs.est.9b03003

Obada, Dauda, & Arhin. (2016). Flame Temperature Characteristics and Flue Gas Analysis of an Improvised Biogas Burner. The West Indian Journal of Engineering, 39(0511–5728), 4–8. https://sta.uwi.edu

Striūgas, N., Paulauskas, R., Skvorčinskienė, R., & Lisauskas, A. (2020). Investigation of Waste Biogas Flame Stability Under Oxygen or Hydrogen-Enriched Conditions. Energies, 13(18), 4760. https://doi.org/10.3390/en13184760

Abdel-Hadi, M. A. (2019). Determination of methane content by measurements of flame temperature and voltage from biogas burner.. Https://doi.org/10.21608/mjae.2020.110168

Ketut, C. N., Agung, S., Mekro, P., Heri, H., & Bachtiar. (2018). The flame characteristics of the biogas has produced through the digester method with various starters. *IOP Conference Series: Materials Science and Engineering, 299(1), 012091.* https://doi.org/10.1088/1757

Budiyono, B., Syaichurrozi, I., & Sumardiono, S. (2013). Biogas production from bioethanol waste: the effect of pH and urea addition to biogas production rate. *Waste Technology, 1(1).* https://doi.org/10.12777/wastech.1.1.1-5

Schroeder, V., Schalau, B., & Molnarne, M. (2014). Explosion Protection in Biogas and Hybrid Power Plants. *Procedia Engineering, 84, 259–272.* https://doi.org/10.1016/j.proeng.2014.10.433

Rajendran, K., Aslanzadeh, S., & Taherzadeh, M. J. (2012). Household Biogas Digesters—A Review. *Energies, 5(8), 2911–2942.* https://doi.org/10.3390/en5082911

Hakawati, R., Smyth, B. M., McCullough, G., De Rosa, F., & Rooney, D. (2017). Most energy efficient route for biogas utilization: Heat, electricity or transport. *Applied Energy, 206, 1076–1087.* https://doi.org/10.1016/j.apenergy.2017.08.068