Eco. Env. & Cons. 28 (4) : 2022; pp. (1937-1945)
Copyright@ EM International
ISSN 0971–765X

DOI No.: http://doi.org/10.53550/EEC.2022.v28i04.043

An Investigation into Delineation and Contriving of Bio Gas with Special Reference to Household Use

Hanumant Singh Chouhan*

Department of Chemistry, S.M.C.C. Govt. College, Aburoad 307 026, Rajasthan, India

(Received 22 April, 2022; Accepted 7 June, 2022)

ABSTRACT

The tremendous increase in global energy use during the 1980s has been mostly fuelled by fossil energy resources. In 2018, fossil fuels provided around 85 % of the world's largest total primary energy supply. Caused by climate change, affordable energy costs, more dispersed production, and environmental factors, biomass to energy transfer takes increased as of 65 GW in 2010 to 120 GW in 2019. Anaerobic digestion, digestion, and landfill processes are more suitable for wastes with high moisture. Just at end of 2019, the worldwide output of biogas plants was estimated to be at 19.5 GW. Due to their high moisture content and degradation rate, organic pollutants are among the most popular feedstocks for producing biogas from trash, including home wastes. The organic portion of municipal waste is represented by these input materials, which are classed as Organic wastes. This study describes the various application of biogas with special reference to household use and how it is important in today's scenario.

Key words: *Biogas, Global warming, Greenhouse gas emission, Climate change, Anaerobic digestion, Organic waste.*

Introduction

The advantages of biogas ar e evident in an era of serious changing climate and imminent fossil energy collapse. It's a clean, renewable energy source that produces no net greenhouse gas emissions (Popp *et al.,* 2014). Yet, at least in the industrialised world, its promise has largely been unexplored. Based on my research and knowledge, it is believed that home-produced biogas is a highly promising technology that has finally reached its peak. It is observed that it has the potential to spark a home green energy movement if we let it (Issa Korbag *et al.*, 2020).

Once organic matter is deteriorated by micro-organisms in an anaerobic ecosystem, gas is generated. Methane (CH_4 50-75%) and carbon dioxide make up the majority of biogas (CO_2 25-50 %) (Hashemi *et al.*, 2021). Water, sulphur, oxygen, and hydrogen sulphide are some of the other elements of biogas. There are four stages to digestion: acidogenesis, hydrolysis, acetogenesis, and methanogenesis. These four steps must all be available at the same time to establish a stable anaerobic system. Methane, which is created during the methanogenesis step, is the energy carrier in biogas (Olivia Córdova *et al*., 2020).

The resultant combination may be used as a source of energy for cooking, lighting, or heating water or space once the biogas has been filtered to eliminate hydrogen sulphide. It may be compressed and used as automobile fuel. Biogas may be utilised to produce power or processed and put into the gas grid on a commercial basis (Awe *et al.*, 2017).

Food loss, animal wastes, and agricultural leftovers are examples of organic materials used to make biogas. Biogas is produced and captured in certain commercial products using sewage. Anaerobic decomposition of biodegradable organic compounds, including manure, food processing wastes, produce biogas, and energy crops, waste water treatment sludge, which is predominantly a combination of methane and CO_2. The anaerobic digestion procedure takes place in airtight biogas digesters, and it may take anywhere from a few hours. Temperatures of 20 to 45 ^{0}C are usual for anaerobic digestion (Manyi-Loh *et al*., 2013). The feedstock storage, reception and mixing area, digester or reactor, gas holding, and digestion residue storage are all components of a biogas system. There are many different kinds of biogas digesters, and their geographical and environmental appropriateness should be considered to maximise output.

Biogas, unlike fossil fuels, is naturally renewable since the situationstays produced as of"biomass", in addition so this causestays effectively solar energy replacement due to "photosynthesis" mechanism. "Anaerobic digestion (AD) biogas" would nonsolitarily improve nation'senergy, hamper position, nonetheless correspondingly help considerably to natural resource conservation and environmental protection (Nikolausz *et al*., 2021).

Biogas is made up entirely of biogenic materials. This naturally occurring biogas travels into the atmosphere, and its main element, methane, contributes significantly to global warming. Over the last several decades, methane has been utilised as major fossil fuel and processed into electricity, transportation, and heating. Although natural gas resources account for the majority of methane usage and usage today, bio-methane generation from waste recycling methods has expanded significantly. Over the last nine years, it has increased its output potential by 4%. Currently, over 3.5 million tonnes of biomethane are generated across the globe, with a capacity of over 700 million tonnes. This does not rule out the possibility of converting methane from a variety of natural resources. In other terms, biogas infrastructures depend heavily on specialised equipment and the accessibility of management and control mechanisms (Nevzorova *et al.,* 2019a). As a result, a sustainable business to create bio-energy from green and renewable natural resources may be constructed and executed.

Biogas is used in modern large-scale plants in developed nations. Biogas is often used to create heat, energy, and power. Numerous industrial potentials intended forthe situation use cutting-edge"biogas plants as a natural gas" alternative is also existence pursued. According to the statistics studied, worldwide policies and initiatives have resulted in a steady growth in biogas generation (Abanades *et al.,* 2021). As a 0.5 percent contribution of renewable energy, or 12.8 GW, is projected to be completed in the transportation sector by 2020, biofuel manufacture consumes remained designated by way of the key basis of this strategy in dissimilar areas. It's crucial mentioning that bio-gas generating had better not be considered as a threat to "food production". Biofuels are mostly made from cellulosic and lignin wastes as a result of this.

Biogas generation for residential cooking requires a cost-effective digester with a small enough size for domestic usage. The waste is combined with water in any digester to provide the ideal atmosphere for bacteria to degrade the "biomass". Because this is an anaerobic procedure, it must take place in an airtight tank without the availability of oxygen. The biogas condenses at the tank's top, where it is gathered and piped to the consumer (Usack, *et al.,* 2014). The slurry must be collected from the tank on a regular basis. It may also be used as an agricultural fertilizer. A variety of styles have arisen based on this premise. Digesters are available in a variety of shapes and sizes, ranging from "1 m^3" for a small domestic unit to 10 m^3 for a normal agricultural plant and over "1,000 m^3" for a big plant.

A typical "small-scale biogas system" for home usage will have the following components:

- Raw, slurry, liquid, solid animal, and semi-solid, human, or agricultural waste are all collected in this place.
- The anaerobic digester is a kind of anaerobic digestion.
- Storage of slurry
- Gas handling includes the following components: pipework, a gas meter, a gas pump or blower, a pressure controller, and a condensate drain.
- Cooker, boiler, or lighting equipment are examples of end-use devices.

The article Varieties of Biogas Digesters and Plants show a variety of designs made of diversere sources and at varied prices.

Fixed-dome plants, such as the one seen, are long-lasting yet costly. If this is out of reach for most families, the "Low-Cost Polyethylene Tube Digester models used in Latin America" may be a viable option (Nevzorova, *et al.,* 2019b). The diagram below, courtesy of "GIZ/EnDEV Bolivia", depicts a biogas supply route from that kind of digester to the house's stove through a storage tank.

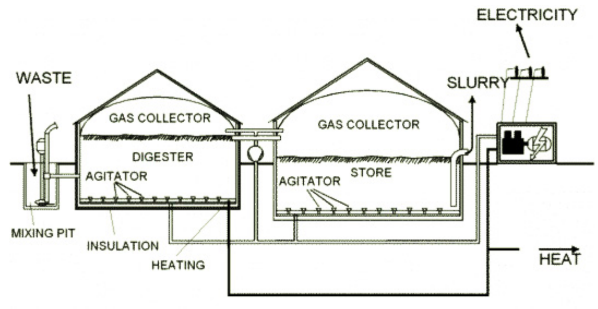

Fig. 1. A Movable Dome Plant in Action

Contriving of Biogas

Food Waste

Every year, over 30% of the world's food supply is lost or squandered. The United States generated around 133 billion pounds of food waste in 2010, largely from the home and commercial food sectors. Agriculture, dairy, and other businesses may benefit from biogas systems by reducing waste water treatment costs. It may help minimise reliance on foreign oil, cut GHG emissions, enhance the local ecology, and create new employment by converting garbage to power (Abdel-Shafy *et al*., 2018). Biogas plants also allow for mineral recycling in food and water supplies, lowering the requirement for petrochemicals and mined biofertilizers alike. The majority of this trash is disposed of in landfills, where it decomposes and creates methane. Although landfills can collect the biogas produced as a consequence of organic waste disposal, there is no way to recover the nutrients contained in the organic waste. In 2015, the Environmental Protection Agency (EPA) and the United States Department of Agriculture (USDA) established penalty areain the direction of decrease nutrition left-overdirected to landfills by half by 2030. Food will still need to be recycled even if this goal is met. That's a lot of energy! Using 100 tonnes of food waste each day, anaerobic digestion could power 800-1400 households for a year. Food service oil, fat, and grease might be fed toward an anaerobiotic digester to improve bio-gas output.

Landfill Gas

In the US, landfills constitute the third base greatest origin of "human-related methane emissions". Landfill gas contains same "anaerobic bacteria" that break down biological material to make biogas, in this case landfill gas (LFG). Rather than letting landfills gaspass through the environment, it may be captured and converted into energy. Land plants in the US produce around "17 billion kilowatt-hours" of energy each year and provide 98 billion cubic feet of landfill gas toward "natural gas pipelines" or to end-users directly (Baral *et al.*, 2015). In 2015, the average American home used roughly "10,812 kilowatt-hours" of electrical energyapiece year.

Animal Waste

A 1,000-pound dairy cow generates 80 pounds of dung every day on average. Before being sprayed to fields, this manure is often held in holding tanks. Manure not only produces methane as it decays, but may also contribute to nutrient overload in streams. Despite the fact that cattledung supervision produced roughly 10% of altogether methane releases cutting-edge the US in 2015, just 3% of animal waste is recycled using anaerobic digesters. Anaerobic digestion may decrease "greenhouse gas emissions, smells, and up to 99 % of manure pathogens" when animal dung is utilised to create biogas (Zaks *et al*., 2011). According to the EPA, 8,241 animal biogas systems have the capacity to create approximately "13 million megawatt-hours" of electricity per year.

Wastewater Treatment

Numerous waste water conduct facilities currently have "anaerobic digesters" on site to control sewage sludge, which is the objects detached during the primary treatment. Instead of using the biogas produced, many "WWTPs" just flare it. Only 860 of the 1,269 anaerobic digester-equipped wastewater treatment plants use the biogas generated. With anaerobic digestion, which processes over "5 million gallons per day," the US could reduce CO_2 emissions by 2.3 million metric tonnes per year, or the equivalent of 430,000 passenger automobiles (Kasirga, 2021).

Crop Deposits

Stalks, straw, and plant trimmings are examples of crop wastes. Some leftovers remain leftward taking place the ground to help maintain the soil's biological material anddampness while also preventing erosion. Higher crop yields, on the other hand, result in more residues, which can be removed in a sustainable manner. Sustainable harvest rates depend on crop, soil, and weather conditions. A price of $60/dry tonne is estimated by the US Department of Energy based on sustainable harvest rates (Popp, *et al.*, 2012). Due to their high lignin concentration, crop wastes are commonly co-digested with other organic waste.

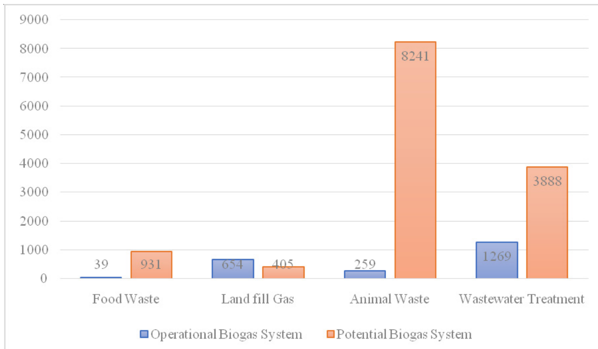

Fig. 2. In the US, the current amount of existing and prospective biogas plants is broken down by feedstock.

Advantages of Biogas

Biogas has several advantages, the most important of which is that it is renewable. While oil and other fossil fuel output will ultimately peak and drop, biogas production will continue as long as the light shines and plants can grow. Because the CO_2 released into the environment when biogas is burned is equal to the CO_2 pulled down from the environment when the organic material was initially cultivated, biogas has zero net greenhouse emissions.

Methane is created when organic matter degrades under anaerobic circumstances, as previously stated. Each year, between 590 million and 800 million tonnes of methane are emitted into the atmosphere, according to estimates (Singh *et al.,* 2014). This is terrible news for the environment since methane is a significantly more powerful greenhouse gas than CO_2 pound for pound. When methane is caught in a biogas system, it is eventually transformed to CO_2 whenever the fuel is burnt. Biogas has no net emissions since the CO_2 would have ended up in the environment anyhow due to natural deterioration.

There are additional advantages as well. In most cases, the organic matter utilised in biogas digesters is a waste product. We can minimise the quantity of food waste and some other organic items transported to landfills by utilising biogas.

Biogas systems can create nutrient-rich sludge that may be watered down and used as a fertiliser for gardens or fields. All of these may contribute to greater energy independence, enhanced resilience, and cost savings.

Environmental advantages – Biogas cook stoves offer a favourable environmental efficiency that is only rivalled by solar cook stoves, with combustion efficiency and particle emissions profile that is equivalent to liquefied petroleum gas (LPG) or ethanol (Desk *et al.,* 2021). Emissions from biogas decomposition are avoided, minimising the emission of pollutants such as carbon monoxide, black carbon, and methane. Biogas stoves eliminate the usage of wood or charcoal, both of which are typically derived from non-sustainable sources.

Health advantages - It is estimated that "household air pollution (HAP)" causes almost 5 million demises per year throughout the globe (WHO, 2012). As assessed by saved disability-adjusted life years, biogas stoves minimise HAP and related disorders (aDALYs). Women and children who are present while cooking gets the highest health advantages (Mortimer *et al.,* 2012). The decrease of quantities of decaying organic waste and related pathogens, which is utilised to make biogas, has other health advantages.

Economic and social benefits – Even though residential biogas digesters have significant upfront prices, ranging from $500 to $1500, they also have some of the lowest annualized basis costs of all technological alternatives for cooking in impoverished locations such as Sub-Saharan Africa, taking into account both capital and operational expenses. They may also enhance rural communities' lives by increasing agricultural productivity using biogas byproducts including such slurry and fertiliser. Biogas digesters significantly decrease the duration of hours that children and women must spend gathering wood, allowing women to engage in profitable enterprises and children to attend school.

Barriers to deployment – Domestic biogas's output potential has yet to be completely realised. Limited awareness of biogas applications, the unit cost of installation, a lack of skilled labour for installation and operation, insufficient and intermittent government support, feedstock accessibility, the requirement for behavioural and social acceptance, consistent maintenance, and competition from fossil fuel-based alternative solutions are among the deployment barriers. Subsidies are sometimes required to minimise the initial cost of installing biogas equipment for cooking (Katarzyna *et al.,* 2012).

International support – Numerous global development assistance programmes are assisting national or subnational initiatives to build low-cost household biogas systems. Biogas systems may also be made more affordable by using prefabricated biogas digester components made of fibre, plastic, or lightweight bags. Continuing to invest in the biogas production chain, from installation to upkeep, may help to lower costs and stimulate system implementation.

Uses of Biogas

Using Biogas to Generate Electricity

The majority of biogas is used to generate energy in agricultural production Anaerobic Digestion Plants where it is produced. This is the first of our biogas applications, which required just modest biogas cleaning (Winquist *et al.*, 2019). Biogas from landfills is included. Before landfill biogas is utilized in this fashion, some water cleansing may be needed. Before usage, a molecule called siloxane, which forms hard deposits within engines, may be removed from landfill gas gathered and combusted in engines to generate energy.

Biogas is readily combusted in huge, tough gas engines similar to those that run on diesel fuel in a less harsh form. By burning the biogas in the vicinity of oxygen, the resulting energy may be utilized immediately for cooking. Denmark's government, which has now been joined by several nations, has chosen to form planned collaborations to advance biogas applications (Bhuvaneshwari *et al.*, 2019). It's utilized in cars that operate on natural gas, electricity, and hydrogen, among other things. By 2020, they want to have 200,000 EV charging stations in place.

Biogas to Biomethane Conversion

Another biogas use is to convert "biogas to biomethane" by removing carbon dioxide and water, and minor quantities of H_2S and other impurities. Methane is also a component of traditional natural gas. To put it another way, "renewable natural gas is biomethane" which has been purified to fulfil the quality requirements of natural gas pipelines.

Utilization of Biogas in the Transportation Sector to Power Automobiles

Biogas can be compressed simply and utilized to power vehicles. Biogas may also be used as a fuel for natural gas cars because of the decoupling of generation and consumption. Biogas converted to biomethane and utilized as a fuel may help to preserve the environment, improve the security of supply, and minimize noise pollution. When cleaned, biogas is virtually the same as natural gas, with the added benefit of being renewable and never running out.

The usage of natural gas as a fuel source will be influenced by government inducements and infrastructure concentration. Like global market criteria for fuel efficiency and greenhouse gas emissions grow more demanding. Natural gas may help cut carbon emissions, but biogas is much better (Gielen *et al.*, 2019). It is practical to convert automobiles to utilize methane as fuel while still being able to use conventional gasoline when they are out of range of a gas recharging station. Several firms in Italy and the United States provide gear for converting petrol engines to run on natural gas or gasoline. Aside from methane, natural gas includes other higher alkanes. It has a greater calorific content than pure methane because of this.

Delhi, India's capital, is home to the nation's first public transportation fleet, which operates ontwo forms of unsoiled fuel:

- RNG
- CNG

As per "Indraprastha Gas Ltd, Delhi" government venture that is the only provider of Compressed Natural Gas in the city, around 16,000 buses in Delhi operate on CNG. This group was formed to exchange knowledge and experiences to help India

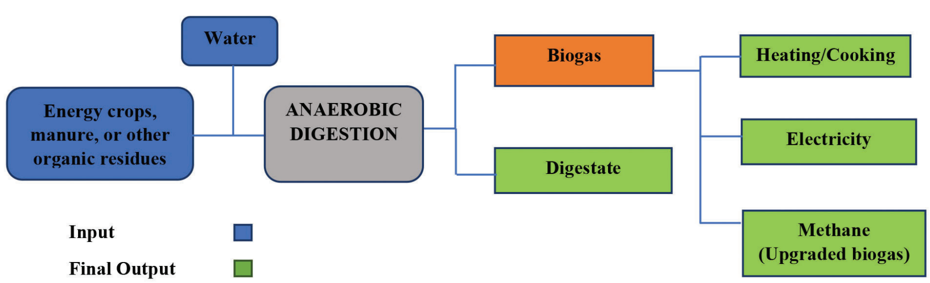

Fig. 3. Using Biogas to Generate Electricity

develop sustainable energy systems, with a concentration on biogas (India Infoline News Service. 2021). Sweden is leading the way in "biogas technology", employing it for heating, electricity generating, and automobile fuelling.

Biogas Combustion in Residential Gas Stoves

Biogas may be used in gas stoves, lighting, and motors in the same manner as natural gas can. When compared to natural gas, which includes 80 to 90% methane, this is a significant difference. Biogas like fuel for gas stoves relieves strain on firewood fuel supply and minimizes petroleum product usage. The usage of biogas has the advantage of lowering the ever-elevated demand for home firewood fuels (Gross *et al.,* 2017). Such demand has resulted in extensive deforestation. Deforestation will be reduced when biogas generation becomes more widely used.

Aside from bio-digestion, other innovative biogas firms manufacture liquid natural gas from biomaterials using technologies that do not need anaerobic digestion. These are also suitable for use in residential stoves.

The consumption of biogas at the place of wood fuel benefits villagers and the entire neighborhood. Instead of trekking to the forest and collecting wood fuel for several hours each day, they could spend that time caring for their kids. Normalfiery is preferable since it is free, but commercially supplied biogas fuel is sometimes too expensive.

Utilization of Biogas as a Fuel Source for Mobile Electricity Generators

The fifth application of biogas is to power portable energy generators. "Portable gen-sets, which seem to be Internal Combustion (IC) engines paired with an alternator or dynamo, are used in most off-grid residences". The generator sets used to operate on biogas are much the same as used to run on "propane or natural gas" (Baredar *et al.,* 2020). They calculate their regular power use and use it to determine the size of their generator set.

Electricity production is the single greatest usage of fuel on the planet. "Coal provided 41% of the energy, natural gas provided another 21%, and hydro, nuclear, and oil provided the remaining 16%, 13%, and 5%, respectively".

Applying Biogas Carbon Credits to Earn Revenue from CDM Payments in Eligible Nations.

The sixth use of biogas is to generate income via CDM subsidies in passing nations under the Kyoto Protocol of the year 1990. Because it is a greenhouse-gas-neutral and reliable source of energy, green gas or biogas has several advantages for environmental sustainability. The majority of biogas contains 50 to 60 % methane, 35 to 50 % CO_2, and a tiny quantity of hydrogen sulphide (H_2S) and ammonia. Natural gas, on the other hand, has a methane content of more than 80% (Surendra *et al.,* 2014).

Compression of Biogas for Gas Cylinder Filling

Compressing biogas to fill gas cylinders ranks seventh on our list of biogas applications. Biogas can be compressed and then used to power cars in the same manner that natural gas can be compressed to CNG. Biogas is cleaned and improved to natural gas requirements, at which point it is converted to biomethane, which may then be compressed. Many CNG users in Scandinavia have vehicles ranging from tractors to cars to buses that have been constructed or retrofitted to run on natural gas (Shah *et al.,* 2017). RNG from a local biogas plant infrastructure is routed straight to a neighboring fuelling station in several European locations, bypassing the natural gas network.

Direct Biogas to Electricity Conversion in a Fuel Cell

The conversion process of biogas to energy in a fuel cell is the last instance of biogas applications. The gas is used in fuel cells to heat a particular electrical cell. Once heated, this electrical cell produces electricity. Such technique necessitates highly unsoiled gas and costly fuel cells, but it has many promises for the forthcoming. Household heating systems boilers currently exist that, in addition to producing hot water for home heating, also feature a fuel cell that generates electricity (Farooque *et al.,* 2015).

Conclusion

For America's farms, dairies, and businesses, bio-gas structures transform the rate of treating leftover water interested in the cash flow potential. Converting waste to electricity, heat, or automobile gasoline is a long-term solution that can help reduce reliance on imported oil from other countries, reduce GHG emissions, improve the local ecosystem, and create new jobs. Biogas facilities also allow minerals to be recycled in the food and water supply, eliminating the demand for petrochemicals besidesexcavated biofertilizers.

Bio-gas plants stand a leftoversupervision option that may help with a variety of issues and provide a variety of advantages, including cash streams. There is presently the potential for 13,500 new biogas systems to be installed in the US, resulting in around "335,000 construction" employment and "23,000 permanent" positions. Unfortunately, for the sector to attain its full potential, it requires sustained legislative backing. Investment and development in the biogas business are encouraged by consistent support of Farm Bill energy heading programmes and a robust "Renewable Fuel Standard". If the US wants to expand its fuel source while also combating global warming, biogas should be seriously considered.

The global biogas sector grew by more than 90% between 2010 and 2018, thanks to new biogas uses, and further growth, is projected in the future. The biogas sector, on the other hand, differs greatly in various parts of the globe. Different nations have built a variety of biogas systems that are mostly based on the environment, and also energy market and economic chain. The production procedures and specialised uses of biogas have been researched and explored in this study in recent years. The decomposition of organic material in the absence of oxygen creates biogas, which is mostly composed of carbon dioxide and methane. Due to variables such as climate change, affordable energy costs, and growth in distributed production, the use of biogas and the development of its possible uses has gained popularity in recent years. Biogas is an off-grid energy resource that may be utilised for a variety of purposes, including power generation and CHP systems.

It is hoped that good microbial resource management would allow for the recovery of biomass's inherent chemical energy through an efficient AD process. Furthermore, enhanced intensive care and regulation of the AD procedure are required for hourly decision making to increase the procedure's adaptationoutput by reducing the loss of potential methane generation owing to biomass charging rate imbalances.Biomass may be used to establish a healthy recycling industry by recycling organic leftovers, containing nutrients, and returning them to civilization as energy and fuel.

The current research focus is on improving existing technologies for practices that have a positive impact of "biomass-based organic" wastes on biomethane in additionthe thinguses as anordinary gas otherwise automobile petroleum replacement. One of the most current bio-gas uses is hydrogen generation utilising an elevated biogas reforming device. The use of "hydrogen like a clean fuel", particularly for cars, is progressing rapidly. Biogas may also be used in fuel cells, which is a cutting-edge application. Fuel cells have recently advanced to the point where they are appropriate for power production and transportation, with low emissions and great efficiency. Despite the fact that converting "biomass to biogas" using AD already has developed a tangible truth in several nations, the considerable financial risks associated with its implementation need more monetary incentives from governments to encourage long-term shifts in current technology.

Declaration of Completing Interest

The author declare that he has no known competing financial interest or personal relationships that could have appeared to influence the work reported in this paper

Acknowledgement

Author is very much thankful to the Principal and lab boy of S.M.C.C. Govt. College Aburoad (Raj.) who appreciate him for doing such kind of research.

References

Awe, O. W., Zhao, Y., Nzihou, A., Minh, D. P. and Lyczko, N. 2017. A Review of Biogas Utilisation, Purification and Upgrading Technologies. *Waste and Biomass Valorization*. 82: 267–283. https://doi.org/10.1007/s12649-016-9826-4

Abanades, S., Abbaspour, H., Ahmadi, A., Das, B., Ehyaei, M. A., Esmaeilion, F., el Haj Assad, M., Hajilounezhad, T., Jamali, D. H., Hmida, A., Ozgoli, H. A., Safari, S., AlShabi, M. and Bani-Hani, E. H. 2021. A critical review of biogas production and usage with legislations framework across the globe. *International Journal of Environmental Science and Technology*. https://doi.org/10.1007/s13762-021-03301-6.

Abdel-Shafy, H. I. and Mansour, M. S. 2018. Solid waste issue: Sources, composition, disposal, recycling, and valorization. *Egyptian Journal of Petroleum*. 274: 1275–1290. https://doi.org/10.1016/j.ejpe.2018.07.003

Baredar, P., Khare, V. and Nema, S. 2020. *Design and Optimization of Biogas Energy Systems*. 1st ed.. Academic Press.

Bhuvaneshwari, S., Hettiarachchi, H. and Meegoda, J. 2019. Crop Residue Burning in India: Policy Challenges and Potential Solutions. *International Journal of Environmental Research and Public Health*. 165: 832. https://doi.org/10.3390/ijerph16050832

Baral, S. S., Singh, K. and Sharma, P. 2015. The potential of sustainable algal biofuel production using CO 2 from thermal power plant in India. *Renewable and Sustainable Energy Reviews.* 49: 1061–1074. https://doi.org/10.1016/j.rser.2015.04.181

Desk, I. T. W. 2021. October 29. IIT Guwahati creates environment-friendly solution for cook-stoves that saves energy by 25–50%. India Today. https://www.indiatoday.in/education-today/news/story/iit-guwahati-creates-environment-friendly-solution-for-cook-stoves-that-saves-energy-by-25-50-1871234-2021-10-29

Farooque, M., Leo, A., Rauseo, A. and Wang, J.Y. 2015. Efficient and ultra-clean use of biogas in the fuel cell - the DFC experience. *Energy, Sustainability and Society*. 51. https://doi.org/10.1186/s13705-015-0041-0

Gielen, D., Boshell, F., Saygin, D., Bazilian, M. D., Wagner, N. and Gorini, R. 2019. The role of renewable energy in the global energy transformation. *Energy Strategy Reviews.* 24: 38–50. https://doi.org/10.1016/j.esr.2019.01.006

Gross, T., Zahnd, A., Adhikari, S., Kaphre, A., Sharma, S., Baral, B., Kumar, S. and Hugi, C. 2017. Potential of biogas production to reduce firewood consumption in remote high-elevation Himalayan communities in Nepal. *Renewable Energy and Environmental Sustainability*. 2: 8. https://doi.org/10.1051/rees/2017021

Hashemi, B., Sarker, S., Lamb, J. J. and Lien, K.M. 2021. Yield improvements in anaerobic digestion of lignocellulosic feedstocks. *Journal of Cleaner Production*. 288: 125447. https://doi.org/10.1016/j.jclepro.2020.125447

Issa Korbag, Salma Mohamed Saleh Omer, Hanan Boghazala and Mousay Ahmeedah Aboubakr Abusasiyah July 30th 2020. *Recent Advances of Biogas Production and Future Perspective, Biogas - Recent Advances and Integrated Approaches*, Abd El-Fatah Abomohra, Mahdy Elsayed, Zuzeng Qin, HongbingJi and Zili Liu, Intech Open, DOI: 10.5772/intechopen.93231. Available from: https://www.intechopen.com/chapters/72920

India Infoline News Service. 2021, April 1. *Indraprastha Gas ties with Delhi Transport to supply CNG; Stock climbs 2%*. IIFL SECURITIES. https://www.indiainfoline.com/article/news-top-story/indraprastha-gas-ties-with-delhi-transport-to-supply-cng-stock-climbs-2-121040100345_1.html

Katarzyna, B. and Irena, W. B. 2012. Biogas production during multi-component co-fermentation of waste materials. *New Biotechnology*. 29: S48. https://doi.org/10.1016/j.nbt.2012.08.133

Kasirga, E. 2021. Adaptable Pathways Planning with Innovative Quintuple Bottom Line Evaluation of Regional Biosolids Management Options. *Academia Letters*. https://doi.org/10.20935/al1775

Manyi-Loh, C., Mamphweli, S., Meyer, E., Okoh, A., Makaka, G. and Simon, M. 2013. Microbial Anaerobic Digestion Bio-Digesters as an Approach to the Decontamination of Animal Wastes in Pollution Control and the Generation of Renewable Energy. *International Journal of Environmental Research and Public Health*. 109 : 4390–4417. https://doi.org/10.3390/ijerph10094390

Mortimer, K., Gordon, S. B., Jindal, S. K., Accinelli, R. A., Balmes, J. and Martin, W. J. 2012. Household Air Pollution Is a Major Avoidable Risk Factor for Cardiorespiratory Disease. *Chest*. 1425 : 1308–1315. https://doi.org/10.1378/chest. 12-1596

Nikolausz, M. and Kretzschmar, J. 2021. *Current Advances in Anaerobic Digestion Technology*. Mdpi AG.

Nevzorova, T. and Kutcherov, V. 2019a, 2019b. Barriers to the wider implementation of biogas as a source of energy: A state-of-the-art review. *Energy Strategy Reviews.* 26 : 100414. https://doi.org/10.1016/j.esr.2019.100414

Olivia Córdova, Rolando Chamy, 2020. *Chapter 15 - Microalgae to Biogas: Microbiological Communities Involved*. Abu Yousuf. Microalgae Cultivation for Biofuels Production. Academic Press. pp.227-249, ISBN 9780128175361, https://doi.org/10.1016/B978-0-12-817536-1.00015-1.

Popp, J., Lakner, Z., Harangi-Rákos, M. and Fári, M. 2014. The effect of bioenergy expansion: Food, energy, and environment. *Renewable and Sustainable Energy Reviews.* 32 : 559–578. https://doi.org/10.1016/j.rser.2014.01.056

Popp, J., Petõ, K. and Nagy, J. 2012. Pesticide productivity and food security. A review. *Agronomy for Sustainable Development*. 331: 243–255. https://doi.org/10.1007/s13593-012-0105-x

Singh, P., Singh, P. and Gundimeda, H. 2014. Energy and environmental benefits of family biogas plants in India. *International Journal of Energy Technology and Policy*. 103/4 : 235. https://doi.org/10.1504/ijetp.2014.066881

Surendra, K., Takara, D., Hashimoto, A. G. And 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

Shah, M. S., Halder, P. K., Shamsuzzaman, A. S. M., Hossain, M. S., Pal, S. K. and Sarker, E. 2017. Perspectives of Biogas Conversion into Bio-CNG for Automobile Fuel in Bangladesh. *Journal of Renewable Energy*. 1–14. https://doi.org/10.1155/2017/4385295

Usack, J. G., Wiratni, W. and Angenent, L. T. 2014. Improved Design of Anaerobic Digesters for Household Biogas Production in Indonesia: One Cow, One Digester, and One Hour of Cooking per Day. *The Scientific World Journal*. 1–8. https://doi.org/10.1155/2014/318054

Winquist, E., Rikkonen, P., Pyysiäinen, J. and Varho, V. 2019. Is biogas an energy or a sustainability product? - Business opportunities in the Finnish biogas branch. *Journal of Cleaner Production*. 233 : 1344–1354. https://doi.org/10.1016/j.jclepro.2019.06.181

Zaks, D. P. M., Winchester, N., Kucharik, C. J., Barford, C. C., Paltsev, S. and Reilly, J. M. 2011. Contribution of Anaerobic Digesters to Emissions Mitigation and Electricity Generation Under U.S. Climate Policy. *Environmental Science & Technology*. 4516 : 6735–6742. https://doi.org/10.1021/es104227y