

## Review Article

# Recent Advances in Biogas Production

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## Abstract

The biogas production technology is known from past several decades and gets popularize in the last decade for getting a sustainable alternate clean energy resource. The available agricultural waste and animal excreta can be used as a feedstock for the biogas production which makes it more popular alternate and sustainable energy resource. The biogas can be utilized effectively for the purposes of cooking, electricity, transport and other motive power applications. The biogas production helps in energy security, reducing pollution and improving hygienic conditions, therefore providing benefits to society, economy, and environment at the same time make biogas as a sustainable energy resource. The technology is very old, and research in due course added several advancements in process design and feedstock utilization but still, need some improvements for enhanced and linear biogas production.

## Keywords

- Biogas
- Bioenergy
- Biomass
- Technology
- Sustainability

## INTRODUCTION

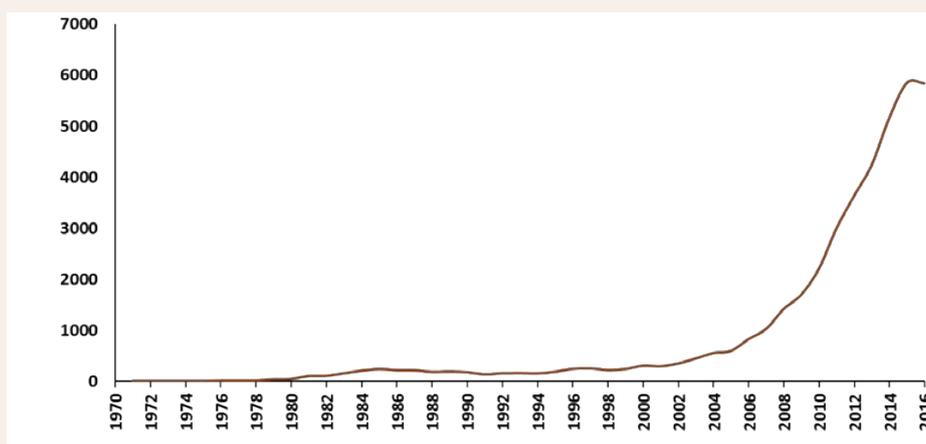
Biogas technology offers an attractive route to utilize a range of lignocellulosic biomass and other organic wastes, such as crop residues, vegetable wastes, cattle dung, food waste and even the organic fraction of MSW. These biomass sources are available in plenty, which has an excellent potential to cater the present and future energy demand, especially in the domestic sector. The anaerobic digestion of biodegradable fractions of wastes is widely recognized as a mature and cost-effective option for producing biogas, a valuable renewable primary energy source. This technology provides a clean and efficient fuel for numerous end uses such as cooking, electricity, transport and other motive power applications.

Beside energy production, the degradation of biomass waste through anaerobic digestion offers other advantages, such as the prevention of odour, disposal solution and improvement in sanitation by destroying pathogens during the process. Moreover, the nutrient rich digested slurry can be utilized as fertilizer for recycling of nutrients back to the fields. Another advantage offered by biogas is to lead to a net reduction of greenhouse gas emissions, since methane would otherwise be released into the atmosphere, provoking a 21-fold higher greenhouse effect than CO<sub>2</sub>. Therefore, it is important to treat organic wastes under controlled conditions to reduce spontaneous dissipation of methane to the atmosphere. The production of biogas will minimize the use of fossil fuels, thereby reducing the greenhouse gas emission, which is in line with Kyoto Summit Agreement.

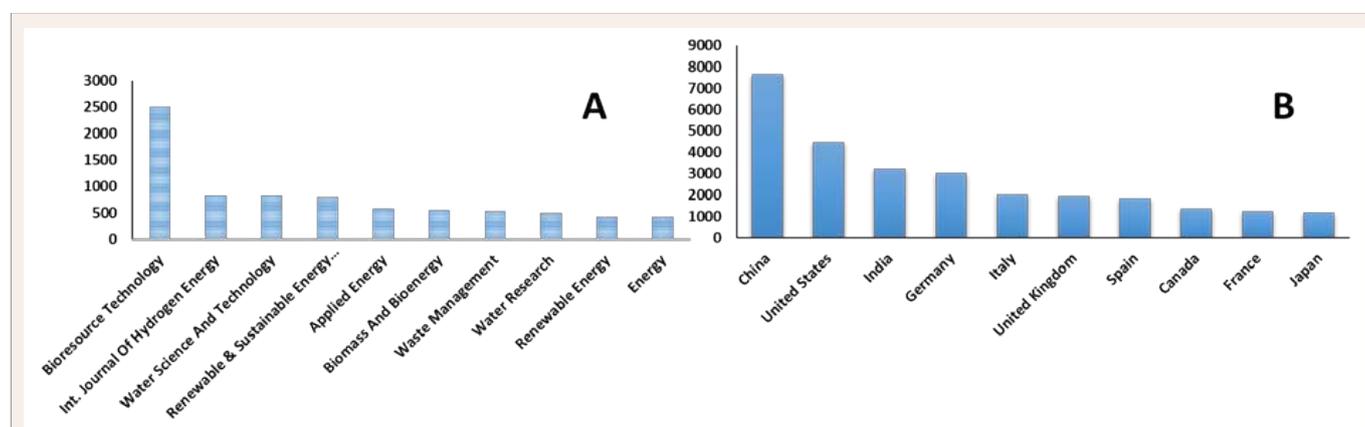
Despite its several advantages, the potential of biogas technology could not be fully harnessed due to limitations associated with the production of biogas. Notably common among these are the large hydraulic retention time (HRT), low gas generation in winter, etc. In an agrarian nation like India where rural electrification is limited and commercial fuels make up only 11% of rural energy use, biogas could go a long way toward improving the energy security and environmental future. Therefore, efforts are needed to remove its constraints and to make this technology more feasible for industrial production and in reach of the rural population. Researchers have examined different techniques to enhance gas production. This article provides a critical analysis of recent research advancement for biogas production and its future perspective for sustainable biogas production scenario.

## SCIENTOMETRIC ANALYSIS

The recent SCOPUS database survey on biogas publication showed 41,512 publications since 1970. The researchers get boosted at the beginning of the twenty-first century, and tremendous work has been reported in the last decade (Figure 1). Presently, more than 150 journals are publishing papers on biogas related research. The top journals publishing research on biogas include Bioresource Technology, International Journal of Hydrogen Research, Water Science and Technology, Renewable and Sustainable Energy Research, etc. (Figure 2A). Researchers from China have published the maximum number of papers amongst the more than 150 countries working on biogas (Figure



**Figure 1** Trend of papers published on biogas (Source: SCOPUS).



**Figure 2** Top ten journals (A) and countries (B) published research on biogas (Source: SCOPUS).

2B). The United States of America is at the second position in publishing research on biogas and India at the third position followed by Germany, Italy, United Kingdom, Spain, Canada, etc.

The survey also showed that maximum publication (more than 75% of total publication) on biogas are published as articles, and more than 12% are published as conference papers (Figure 3A). The majority of research on biogas is focused on Environmental Science (21%), Energy (14%), Chemical Engineering (12%) and Engineering (12%) (Figure 3B). This clearly shows that researchers working on biogas are focused on exploring biogas as clean, renewable alternative energy source.

## PROCESS AND MECHANISM

Biogas production process is an anaerobic fermentation process involves decomposition of complex organic material (biomass), through four groups of microorganisms [1] into fuel and manure. Biogas production process is a multiple-stage process as represented in Figure 4. The hydrolysis of feedstock takes place at the initial stage, and the hydrolytic enzymes make a suitable condition for acid forming bacteria while intermediate metabolites i.e. soluble and insoluble monomers are synthesized. These monomers then further transformed into fatty acids with a small amount of hydrogen. The most frequently detected organic acids are propionic and butyric acids with a small quantity of

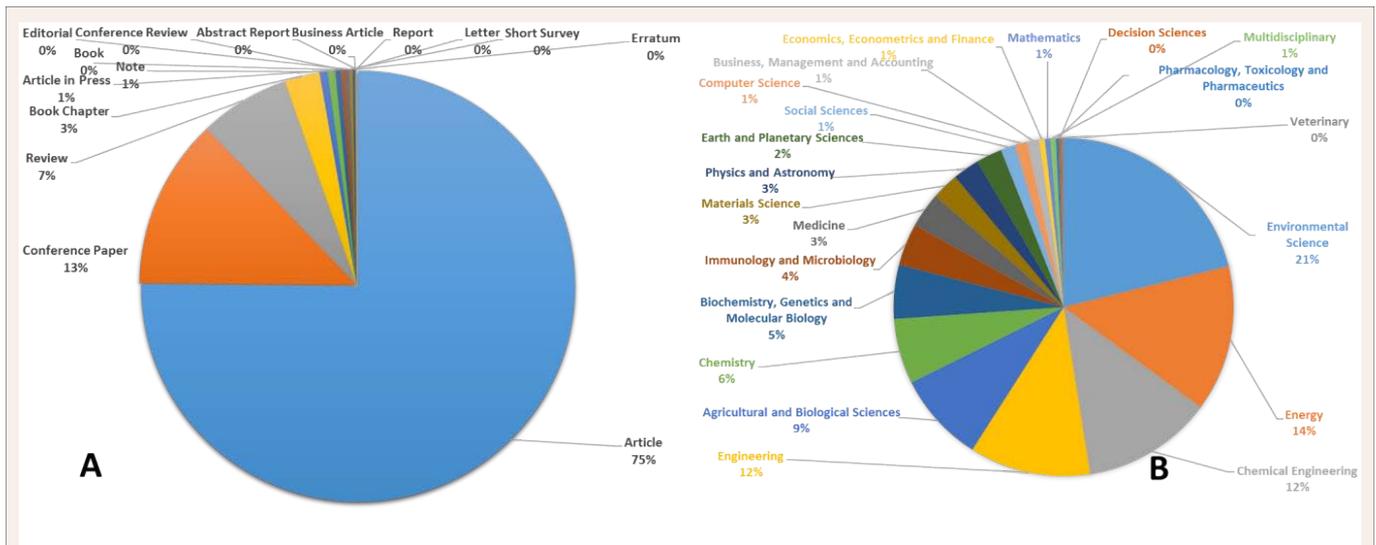
valeric acid. This stage is called acedogenesis (acid formation). At this stage, acetogenic bacteria start functioning and produce acetic acid, and the stage is called acetogenesis. Optimal pH value at this stage is in the range of 5-6. In the acidification stage of organic wastes, the pH of media drops to an acidic condition. At the final stage acetic acid, propionic acid, butyric acids, hydrogen and carbon dioxide are converted into a mixture of methane and carbon dioxide by the methanogenic bacteria.

## Hydrolysis

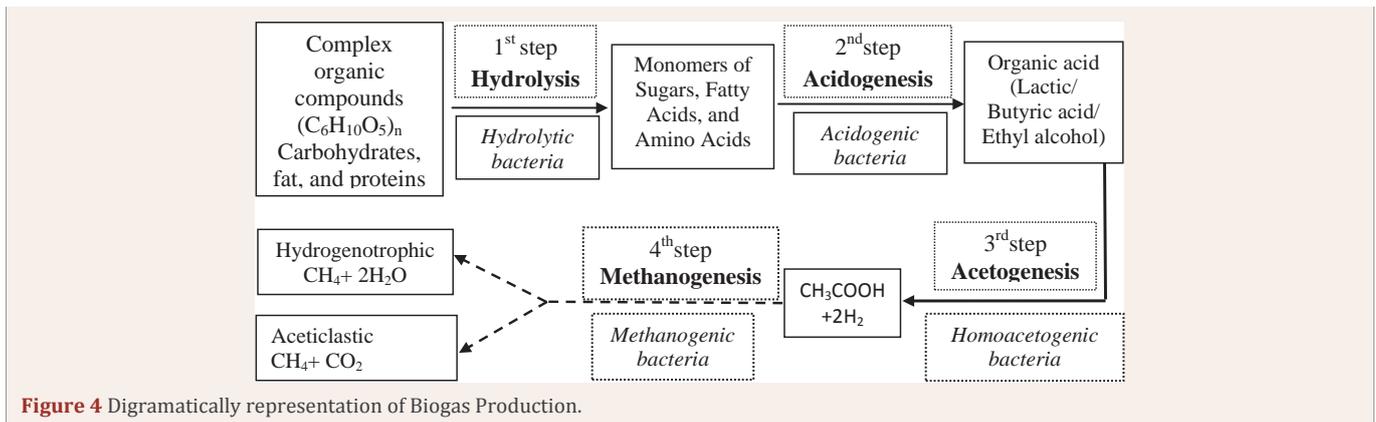
Hydrolysis is the 1<sup>st</sup> step of biogas production, in which the primary components or complex organic molecules of waste organic matter/biomass (carbohydrates, lipids, and proteins) broken down by cellulolytic, lipolytic, and proteolytic bacteria, respectively, into smaller units (monomer sugars, amino acids, alcohols, and fatty acids). Bacteria of genera *Bacteroides*, *Lactobacillus*, *Propionibacterium*, *Sphingomonas*, *Sporobacterium*, *Megasphaera*, *Bifidobacterium* are most common in hydrolysis, including both facultative and obligatory anaerobes. The rate of hydrolysis is typically represented by using first-order kinetics [2].

## Acidogenesis or acid production

Acidogenesis is the 2<sup>nd</sup> step of biogas production, in which



**Figure 3** Percentagewise publication type (A) and publication in subject area (b) (Source: SCOPUS).



the acidogenic bacteria further break down the products (the soluble monomers molecules) of the first step, into short-chain organic acids (volatile fatty acids i.e. lactic, propionic, and butyric acids,  $\text{NH}_3$ ,  $\text{H}_2\text{S}$ , and  $\text{H}_2$ . Alcohols such as ethanol and carbon dioxide ( $\text{CO}_2$ ), is also produced during this process. Similar to hydrolysis, this step also included facultative and obligate anaerobic fermentative bacteria, i.e., *Clostridium spp.*, *Peptococcus anaerobius*, *Bifidobacterium spp.*, *Desulphovibrio spp.*, *Corynebacterium spp.*, *Lactobacillus spp.*, *Staphylococcus spp.*, and *Escherichia coli* [2,3].

### Acetogenesis or acetic acid production

Acetogenesis is the 3<sup>rd</sup> step of biogas production, in which the volatile fatty acids and ethanol produced during acidogenesis are further broken down into acetic acid ( $\text{CH}_3\text{COOH}$ )/acetate ( $\text{CH}_3\text{COO}$ ),  $\text{H}_2$ , and  $\text{CO}_2$  by acetogenic bacteria. Acetogenic bacteria (acetate and hydrogen producing bacteria) such as *Syntrobacter wolini* and *Syntrophomonas wolfei* convert fatty acids and alcohol into acetate, hydrogen and carbon dioxide.

### Methanogenesis or methane production

Autotrophic methanogens, including bacteria from the genera *Methanosarcina* and *Methanosaeta*, perform this conversion

process. Vavilin et al. [4], showed that in spite of the high initial biomass concentration of *Methanosaeta* sp., *Methanosarcina* sp. became the dominant acetoclastic methanogens in the system. 4<sup>th</sup> Stage decreases the oxygen demand (BOD, COD) of residual waste by turning acetic acid to the gaseous products ( $\text{CH}_4$  and  $\text{CO}_2$ ). Some microbial species, called hydrogenotrophic methanogens, can generate methane from the  $\text{CO}_2$  and  $\text{H}_2$  formed as products in previous stages [5]. *Methanobacterium formicidum* was the predominant methanogenic bacteria in cattle dung-fed digesters, followed by *Methanobacterium ruminantium*. Methanogens have very slow growth rates; their metabolism is usually rate-limiting in anaerobic treatment processes.

### KINETICS OF ANAEROBIC FERMENTATION

Various kinetic models have been evolved to explain the anaerobic fermentation process. Monod showed a hyperbolic relation among the exponential microbial growth rate and substrate concentration. In this model, the two kinetic parameters, particularly, microbial growth rate and half velocity constant are deterministic in nature, and these predict the circumstances of the timing of highest biological activity and its cessation. This model can be applied to determine the rate of substrate utilization (rS) by the equation [6]:

$$r_s = q_{\max} \cdot S_x / (K + S_x)$$

Where,  $S$  is the limiting substrate concentration,  $K$  is half constant,  $x$  is a concentration of bacterial cells, and  $q_{\max}$  is the maximum substrate utilization rate.

The above equation is applicable for low substrate concentration.

However, for high substrate concentration, the equation is re-written as:

$$r_s = q_{\max} \cdot x.$$

The Monod model experiences from the impediment that one set of kinetic parameters are not adequate to explain biological process both for short- and long retention times and that kinetic parameter cannot be achieved for some complex substrates. To alleviate constraints of the Monod model while retaining its advantages, Hashimoto developed an alternative equation, which attempts to describe the kinetics of methane fermentation regarding certain parameters. According to this equation, provided below, for a given loading rate  $S_0/q$  everyday volume of methane per size of digester depended on the biodegradability of the biomass and kinetic parameters  $\mu_m$  and  $K$ .

$$r_v = (B_0 \cdot S_0/q) \cdot \{1 - (K/q \mu_m - 1 + K)\}$$

$r_v$  is volumetric methane production rate,  $l \text{ CH}_4 \text{ l}^{-1} \text{ digester d}^{-1}$

$S_0$  is influent total volatile solids (VS) concentration,  $g \text{ l}^{-1}$

$B_0$  is ultimate methane yield,  $l \text{ CH}_4 \text{ g}^{-1} \text{ VS added as } q \text{ @ } \text{€}$

$q$  is hydraulic retention time  $\text{d}^{-1}$

$\mu_m$  is maximum specific growth of microorganism  $\text{d}^{-1}$

$K$  is a kinetic parameter, dimensionless.

Presently, the cattle population is gradually decreasing, but a significant quantity of herbaceous biomass is available for conversion to biogas. About 120 million tons of herbaceous biomass of the annual net generation of 1150 million tons would be adequate to bridge this gap in our country. Biomass as feedstock represents an inexhaustible energy resource that can be used partly or wholly for biogas production. Organic waste, as the main constituent of solid biomass, has a high potential for biogas. The municipal organic waste (food waste), Bio-waste from industry and business activities (e.g. fat, waste from grocery stores, harvest residues of crops) are the valuable source of biogas production [7].

## ADVANCEMENTS IN TECHNOLOGY

Biogas is generated by digestion process under anaerobic conditions whose application is rapidly emerging as a viable means for providing continuous power generation [8]. The anaerobic digestion cycle represents an integrated system of a physiological process of participating microbial community and energy metabolism, as well as processing of raw materials under specific conditions [9]. However, the microbial community is sensitive to variations in the operating conditions applied. Thus, the anaerobic digestion process, if improperly managed, would become unstable and result in reduced biogas production [8]. Recent advances and multi-disciplinary cooperation in biological

sciences and engineering are bringing new hopes for better understanding and direction of the anaerobic digestion processes, and thus a renaissance of this technology [10]. Biogas technology requires the combination of various operations including skilled personnel for the installation and maintenance of biogas plants. Improper solids leading, temperature fluctuations, maintenance of pH for optimal growth of methanogenic bacteria, C/N ratio, the dilution ratio of influent solids content, corrosion of gas holder, pin-hole leakages are some of the technical problems in biogas production and usage.

## USE OF ADDITIVES

Biogas plant performance and gas production rate can be improved by stimulating the microbial activities using various biological and chemical additives under different operating conditions. Additives are often used to provide the ideal nutrient condition for microbes however; its optimal concentration depends on biocenosis and required a close observation of research team [11,12]. The addition of magnesium and calcium salts increased methane generation in addition to reduced slurry foaming [13]. Additives to stabilize fluctuating pH and to reduce concentration of ammonia and hydrogen sulfide are also in use [14]. The addition of some biological additives and subsequent storage for 7 weeks could enhance the biogas and biomethane production per ODM (Optimizing Anaerobic Digestion) when compared to the untreated sample [15]. Crop residues like maize stalks, rice straw, cotton stalks, wheat straw, onion storage waste and water hyacinth, etc. enriched with partially digested cattle dung enhanced gas production in the range of 10–80%. Several inorganic additives that improve biogas production have also been reported, for example, the addition of iron salts at various concentrations ( $50 \text{ mM-FeSO}_4$ ), ( $70 \text{ lM-FeCl}_3$ ) has been found to enhance gas production rate. Cellulolytic strains inoculum like *Actinomyces* and mixed consortia have been found to improve biogas production rate in the range of 8-44% from cattle dung [16]. Addition of commercial zeolite increased biogas production by 15% and calcium carbonate increased performance by 8%. Iron chloride, commonly used to reduce hydrogen sulphide concentration in biogas had no negative impact on biogas production by the addition of  $0.03$  and  $0.06 \text{ g l}^{-1}$  [14]. A list of additives used are presented in Table 1.

## Recycling of digested slurry/slurry filtrate

The recycling of digested slurry along with filtrate, back into the reactor has been found to improve the gas production. Recycling of 50% slurry filtrate mixed with 10% digested slurry can result into about 50% water conservation and 10% increase in gas production [36]. Kanwar and Guleri [37] reported that nearly 60 to 65% more biogas could be produced by recycling the digested biogas slurry. Some designs use vermiculture to enhance further the slurry generated by the biogas plant for use as compost. In an experiment Malik and Tauro [38] used predigested slurry along with 10% effluent recycled slurry in a  $1 \text{ m}^3$  daily fed floating drum biogas digester, an increase of up to 18.8% in gas production in 30 days HRT was observed.

## Variation in operational parameters

Thermophilic digestion has a rate-advantage over

**Table 1:** Additives used for biogas production.

Additives Category	Used Compound/Material	Feed Stock	Result	Reference
Biological Additives	Plant Extracted Aquasan and Teresan	Cattle dung and kitchen waste	Increased Gas yield	[17]
	Lantana Residue, wheat straw, apple leaf litter and peach leaf litter	Cattle dung	1-6% increased gas yield	[18]
	mustard meal/cake	Cattle dung	13.38-63.44% Increased gas production	[19]
	Homo-fermentative and hetero-fermentative bacteria	Maize	22.5% increased gas yield	[15]
	<i>Auricularia auricula-judae</i> (Fungi)	Sweet chestnut leaves and hay	15% increase in biogas production	[20]
	<i>Ceriporiopsis subvermispora</i> ATCC 96608 (fungi)	Yard trimmings	154% increased methane yield	[21]
	Enzymes	Lignocellulosic biomass	Up to 34% increased gas yield	[22]
Chemical Additives	NaOH	Fallen Leaves	24 times higher biogas yield than control	[23]
	NaOH	Wheat Straw	112% increase in methane Yield	[24]
	NaOH	Wheat Straw	47% increase of biochemical methane potential	[25]
	NaOH	Rice Straw	30% higher biogas yield	[26]
	NaOH	lignocellulosic feedstocks	Positive effect of methane yield	[22]
	Lime	Rice Straw	Improved biogas production	[27]
	Ca(OH) <sub>2</sub>	OFMSW	172% higher methane yield	[28]
	Ammonium hydroxide	switchgrass	65% increased methane yield	[29]
	Diluted H <sub>2</sub> SO <sub>4</sub>	sugarcane bagasse	166% increase in methane yield	[30]
	4% HCl or 10% FeCl <sub>3</sub>	Sunflower stalks	21-29% increased methane potential	[31]
	H <sub>3</sub> PO <sub>4</sub>	OPEFB	40% improved methane yield	[32]
	FeSO <sub>4</sub>	Cow dung and poultry litter	40% and 42 % increased Methane production respectively	[33]
	FeCl <sub>3</sub>	swine excreta	60% increased biogas production	[34]
	20 mM sulfate		2 fold increase in biogas production	[35]

mesophilic digestion by its faster reaction rates and higher-load bearing capacity resulting into higher productivity compared with mesophilic anaerobic digestion. Although mesophilic digestion systems afford low methane yields and suffer from poor biodegradability and disadvantages related to nutrient imbalance, they demonstrate better process stability and higher richness in bacteria [39]. Moreover, acidification may occur during thermophilic AD, inhibiting biogas production [8]. The methanogens are very sensitive to sudden thermal changes; therefore, any drastic change in temperature should be avoided. Long-term adaptation of active psychrophilic microbial communities was found to be essential for the efficient treatment of cattle dung at low temperature. Precautions are taken during the installation of biogas plants and coating them with insulating materials also helps in keeping the temperature of digester

within the desired range. To increase gas yield, it is preferred to construct biogas plants sun-facing and in a manner as to protect them from cold winds. Biogas plants should be covered with locally available crop residues for minimizing heat losses from the plants. A simple way to the charcoal coating of ground around the digester had been found to improve gas production in KVIC biogas plant by 7–15% [40]. Solar assisted biogas plants to achieve higher gas yield, particularly during winter months. Hot water used in the slurry preparation also helps to improve the gas production. Recently, co-digestion has taken much attention since it is one of the interesting ways of improving the yield of anaerobic fermentation. Considerable investigations on co-digestion were carried out in the batch fermentation mode, and various researchers have looked out the influence of synergy, due to a balanced mixture composition, on methane yield [41].

Díaz et al. [42], reported that it was likely to relate synergetic outcomes with up to 43% increase in methane yield compared with the expected methane yield calculated from methane potentials obtained for the individual substrates. In fact, biogas production and the stability of the process rely heavily on waste composition, process conditions, and the activity of microbial community in the system. In that sense, for certain mixing ratios, co-digestion may also lead to antagonistic interactions, resulting in methane yields lower than expected [42].

### Innovations in digester designs

In original existing biogas plant designs, several efforts have been made to increase biogas production rate. There are urgent needs to improve the designs of biogas plants to reduce the HRT and enhance gas production rate. Recently a new cost effective family type biogas plant (Konark Model) with high efficiency by changing its shape to spiral was developed. 50% increased gas storage volume compared to 33% that of Deenbandhu and Utkal Model most widely used for their cost effectiveness. In these models, construction cost was reduced by 10–15% (on Deenbandhu) if constructed with brick masonry and by 30–35% if built using Ferro cement technology. It was structurally sound due to its spiral shape and covers least surface area. The gas storage capacity of these models is improved, and short-circuiting had been prevented by providing a baffle wall with holes inside the digester in between inlet pipe and bottom outlet tank. Accumulation of ammonia significantly inhibit biogas production. Using ammonia stripping can enhanced biogas production. Abouelenien et al. [43], developed a bench scale reactor equipped with an ammonia-stripping unit for methane production from chicken manure was developed and operated in repeated batch mode. Abouelenien et al. [43], successfully removed ammonia by means of recycling of biogas followed by gas washing in sulfuric acid to capture ammonia, when chicken manure was anaerobically digested for 4 days at 55 °C and at an initial pH of 8–9. By using this method, 80% of total nitrogen in chicken manure was converted to ammonia and 82% of the produced ammonia was removed.

### Metagenomics approaches

The traditional molecular biology technologies help with identifying only the most abundant microbial populations present in the reactor. Due to their high sequencing depth, the newly developed sequencing techniques make the determination of both the most abundant and also the minor populations possible. The NGS-based metagenomic approach enables following up changes in the microbial community structure starting from the very initial stage to souring of the digester. Coding gene sequences (mRNA) especially those representing critical steps of distinct metabolic pathways can be mapped to judge the functional profiles of microbial communities. The high throughput sequencing-based metagenomic characterization of diverse microbial communities involved in bio-methanation of a variety of substrates has been elucidated with the assistance of 454 pyrosequencing and SOLiD NGS methods [44–46].

Investigations on the microbial community in 21 full-scale anaerobic digestion plants using 454 pyrosequencing of 16S rRNA gene sequences showed that the bacterial community was always

more abundant and more diverse than the archaeal community in all reactors. Moreover, it was found that while acetoclastic methanogens or AUMs were detected in plants digesting sewage sludge, they were absent in co-digestions plants. Hence, methane is generated from acetate mainly *via* syntrophic acetate oxidation in the co-digestion plants [45]. Now a day, most studies have strived to investigate the microbial community inside the reactors without taking into account the whole biogas process chain.

### Cleaning and enrichment of biogas

Apart from CH<sub>4</sub> and CO<sub>2</sub>, biogas can also hold water, nitrogen, oxygen, ammonia, hydrogen sulfide, siloxanes, and particles. Concentrations of these impurities are reliant on the composition of the substrate from which the gas was produced. When leaving the digester, biogas is immersed with water vapor, and this water may condensate in gas pipelines and induce corrosion. Water can be reduced by cooling, compression, absorption or adsorption. By increasing the pressure or decreasing the temperature, water will condensate from the biogas and can thereby be deleted. Cooling can be just achieved by burying the gas line equipped with a condensate trap in the soil. Water can also be eliminated by adsorption using SiO<sub>2</sub>, activated carbon or molecular sieves. These substances are regenerated by heating or a reduction in pressure. Other technologies for water elimination are absorption in glycol solutions or the use of hygroscopic salts.

Hydrogen sulfide is produced during microbiological reduction of sulfur-containing compounds (sulfates, peptides, amino acids). The concentrations of hydrogen sulfide in the biogas can be lowered either by precipitating in the biogas digester liquid or by treating the gas either in a stand-alone vessel or while removing carbon dioxide. Precipitation Addition of Fe<sup>2+</sup> ions or Fe<sup>3+</sup> ions in the form of FeCl<sub>2</sub>, FeCl<sub>3</sub> or FeSO<sub>4</sub> to the digester precipitates the relatively insoluble iron sulfide that is removed together with the digested. The method is mainly used in digesters with high sulfur concentration as a first measure or in cases where H<sub>2</sub>S in the biogas is allowed to be high (e.g. greater than 1.000 ppm).

Oxygen is not usually present in biogas since the facultative aerobic microorganisms should consume it in the digester. But, if there is air present in the digester nitrogen will still be existing in the gas when leaving the digester. Oxygen and nitrogen can be existing in landfill gas if the gas is collected using an under pressure. Those gases can be reduced by adsorption with activated carbon, molecular sieves or membranes. At some extent, these gases can also be removed in desulphurisation processes or some of the biogas upgrading processes. Both compounds are challenging (i.e. expensive) to remove. Hence, their presence should be avoided unless the biogas is used for CHPs or boilers.

Ammonia, a byproduct of proteins degradation is also produced during the process. Amounts of ammonia that are existing in the gas are dependent upon the substrate form and the pH in the digester. Ammonia is typically separated when the gas is dried or when it is upgraded. A separate cleaning step is therefore frequently not necessary.

It is important to minimize the loss of methane to achieve an economically viable upgrading plant. It is also important to

reduce the methane slip since methane is a strong greenhouse gas. Thus the release of methane to the atmosphere should be kept to a minimum by treating the off-gas, air or water streams leaving the plant even though the methane cannot be utilized. Methane can be present in the off-gas leaving a PSA-column, in air from a water scrubber with water recirculation or in water in a water scrubber without water recirculation.

Dry digestion is an innovative technology that allows direct biogas production from solid-state organic wastes. The content of solid organic wastes can reach 35%, which is considerably higher than that in traditional anaerobic digesters (8%). Normally, a solid organic waste content of 20% is more suitable. Dry digestion cannot only improve gas production rate and efficiency per tank volume but also simplify the operation and reduce the cost. The digested products can be directly utilized as fertilizers or soil conditioners without dewatering. With all these advantages, the dry digestion technology is attracting the interest of users for the treatment of municipal solid waste and lignocellulosic waste [47].

## SUSTAINABILITY

The biogas production is sustainable, renewable, carbon neutral and reduces the dependency on imported fossil fuels. Often operators or beneficiaries of biogas plants can become entirely energy self-sufficient. They produce the heat and electricity they consume. The Indian Renewable Energy program has led to a considerable increase in the use of biogas in various part of the country. However, increasing biogas production must present ecological sense and not create conflict with the sustainability objectives of environmental conservation. There must, therefore, be a careful consideration of the overall conditions.

The efficiency of the fuel usage is one of the primary criteria for the selection of a solution to the unsustainable use of biomass as energy. Burning of biomass in a traditional stove and dried dung's heating efficiency can be raised from 10-15% to about 25- 30% by using better-designed stoves which can also save fuel [48]. The heating efficiency of biogas from dung would be raised to 60% [49]. Indoor climate will also be improved as a result of using clean biogas stoves instead of burning firewood, straw, and dung cakes.

Biogas can have vital health benefits, mainly in rural areas. According to the Integrated Environmental Impact Analysis carried out by Biogas Support Program for 600 biogas users and 600 non-users, 4% more non-biogas users have respiratory infection than those who own biogas plants [50].

The human and animal wastes are loaded with pathogens. The biogas technology helps in improvement of hygienic conditions through reduction of pathogens, worm eggs and flies. The pathogens typical of human waste will completely be eradicated by the overall digestion process in acidifying and methanogenic stages of anaerobic digestion. High temperatures and long retention times are more hygienic as it kills most of the pathogens. The period taken for killing principal organisms in biogas plants are one or two weeks for typhoid, paratyphoid, cholera and dysentery bacteria, three weeks for hookworm and bilharzia, tapeworm and roundworm die completely when the fermented slurry is dried in the sun. Thus by linking biogas plants to the toilets, rural population and people residing in the slums in and

around municipalities have been provided with good sanitation facilities and help in securing hygienic conditions.

The open exposure of manure heaps resulted in the loss of nutrients mainly nitrogen, potassium and some amount of phosphorus and others through volatilization and leaching [51]. Biogas technology is useful in manure management which reduces nutrient losses from the manure. The biogas slurry is very relevant input to sustainable agriculture which surpasses the negative problems of the energy-intensive chemical input based agriculture like global warming, soil erosion, degradation of ground water, biomagnification of pesticides, etc. Use of biogas slurry in proper combination with chemical fertilizer is one of the major steps in integrated nutrient management for sustainable agriculture [52]. Biogas slurry can solve problems of soil degradation in areas where earlier dung has been used as a burning fuel and save cost in purchasing chemical fertilizers, bring revenue to the household [48].

Many local jobs are created around biogas projects. By 2000, almost 200000 permanent jobs set up by more than 2 million biogas plants in India. During the year 2000-2001 alone, 164 thousand biogas plants were constructed, generating employment to the tune of 5 million man-days [53]. Apart from these, biogas plants have provided many indirect social benefits; such as the decline in the drudgery of rural women and children connected in the gathering of fuelwood from long distances, drop in the incidences of lung and eye infection from cooking in smoggy kitchens and an overall advancement in the standard of living. The daily time spent in feeding a small biogas digester could be as little as 15 minutes compared to several hours in biomass collection. Time consumed cleaning pots, and other kitchen equipment can also be lowered since biogas does not create as much soot as biomass. Hence women and children would have more time for education when they do not have to spend as much time collecting firewood and other biomass fuels [54].

## FUTURE PROSPECTS

The fossil fuel consumption has resulted in negative impacts on environment and society. The biogas technology provides clean alternatives for cooking, lightening, and other application. It also moderates air pollution and reduces the time needed for traditional biomass collection, especially for women and children. The slurry is an additional bonanza as a clean organic fertilizer that potentially increases agricultural productivity, nutrient cycling, and energy balance. Thus, anaerobic digestion is considered an important component of the global strategy to improve energy security and environmentally safe by providing an alternative to fossil fuels for sustainable development. It is a suitable tool for developing countries rich in livestock and agricultural sector for maximizing the use of scarce resources and provides significant benefits to human and ecosystem health.

The success of biogas production will come from the availability of low costs and the broad variety of usable forms of biogas for the production of heat, steam, electricity, and hydrogen and the utilization as a vehicle fuel. Variety of feed stocks, such as crops, grasses, leaves, manure, fruit, and vegetable wastes or algae can be used, and the process can be applied to small and large scales. This allows the production of biogas at any place in

the world. For an increased spreading of biogas plants, further improvements in the production process efficiency, and the development of new technologies for mixing, process monitoring, and process control are necessary. Furthermore, the influence of the microbial community structure on process stability and biogas yield requires further efforts and must be analyzed in more detail.

Recent research results have demonstrated that substantial variations in the community structures occur during the ongoing fermentation process which influences the process efficiency. Molecular analyses have shown the presence of numerous recently unknown bacteria which may have a significant impact on the degradation process. A major potential for increasing the biogas yield also has the pretreatment of substrates and the addition of micronutrients. Important for the future is also a better process control. Presently, there are only a few sensors available that are sufficiently robust to monitor online. With the increasing number of biogas plants, also an improvement of the effluent quality is necessary, to avoid a contamination of groundwater with pathogens and nutrients.

## CONCLUSION

Biogas is an alternate and green energy resource which can utilize number of organic waste material as a feedstock. The process of biogas production is simple and can run with ease. The production of biogas utilizing the available agricultural biomass wastes is an opportunity to reduce the greenhouse gas emission due to improper disposal of these wastes. It also strengthens the energy security and reduces the fossil fuel consumption. This is a sustainable alternative energy resource, which is capable of providing benefits to society, economy, and environment. Efficient biogas utilization can contribute toward promoting greenhouse gas reduction and creating a recycling society. However, efficient conversion of feedstock to biogas and delayed gas storage technology development prevents the effective use of biogas.

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