Microbial and Biotechnological Advancement in Biogas Production

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Abstract

Energy crisis, solid waste management, ever-increasing CO_2 and methane levels, unemployment, deforestation, increased energy generation cost, and depleting fossil fuels are some current challenges faced by developing countries. The biogas production is a sustainable, lenient, and affordable approach to address these issues. This chapter focuses on the history of biogas digesters and their evolution, feasible techniques for biogas production, and methods to enhance biogas quality. It highlights the advantages and limitations of fixed dome digester, floating drum digester, and plug flow digester. Organic waste such as animal dung, food waste, agricultural waste, municipal solid waste, industrial waste, and sewage sludge can be used as feedstock to produce biogas in digesters. Acetic acid produced from glucose and water in acetogenesis process is transformed into methane and by-products through methanogenesis. The efficient production of biogas is carried out by a complex microbial process in which an appropriate environment is necessary for the multiplication of microbes and their proper functioning. Biogas generated at low temperatures using psychrophilic enzymes has a low methane content; however, other factors such as pH, oxygen content, and salt concentration also affect microbial activities and hence the quality of the biogas. The electrical energy produced by biogas from agricultural waste feedstock is carbon zero. In Asia, biogas production is the need of the time and will not only contribute towards a low carbon economy but also will address the longstanding issue of deforestation and environmental pollution. If increasing energy demands of a growing population in Asia and Africa are addressed

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through this renewable approach, then it will enhance the energy security and environment integrity of these two continents.

2.1 Introduction

The increasing solid waste generation and its mismanagement is a global issue, causing serious environmental pollution and human health issues (Zavodska 2003). Uncontrolled urban sprawl has further added salt to injury and made solid waste management (SWM) a challenging problem (Ghose et al. 2006). Legal, financial, and economic aspects associated with it have highlighted this issue in developing countries on a regional, local, and national level (Palabiyik 2002). There cannot be a single panacea to this problem. Every city and state has to develop its SWM system according to the physical and geological setup coupled with the nature of waste being produced (Monavari et al. 2016). Developed countries have successfully developed an integrated waste collection and disposal system, while developing countries, mainly due to lack of capacity building and technological advancements, are left with the only option of open dumping. SWM system of Pakistan, like other developing countries' systems, is also not immune to these mismanagement issues and serves as grave environmental hazards of the time. Even the most advanced urban localities have 57% of their housing societies equipped with a formal disposal system. The situation is more alarming in small towns where only 2/5th of the population has access to a decent waste collection system (Khan et al. 2016).

This open dumping or somewhat decent disposal techniques not only pose severe environmental hazards in the form of land, water, and air pollution but also additionally release around 590–880 million tons of methane. This is the outcome of the biological decomposition and degradation of organic matter in waste through microbial activities (GATE, GTZ 2007). The methane contributes 17% of total greenhouse gas emissions, making it a potent greenhouse gas. The global warming potential of methane is 21% over CO_2. Since 1750, its concentration has increased from 15% to 1800 ppm. In terms of total radiative forcing (TDF), it accounts for 20% (IPCC 2001, 2007). China, India, United States, European Union, and Brazil are ranked as the top economies with maximum methane emissions (Climate Analysis Indicator Tool 6.0 Version 2009). Agriculture is the primary source of GHG emissions, and it contributes 14% of the total methane emission. Livestock and paddy rice are also leading causes of methane emission, and Livestock makes up 37% of anthropogenic methane emissions (Korres et al. 2013).

Figure 2.1 provides an account of various GHGs emitters in Pakistan. The energy sector has been responsible for most of the GHG emissions in the past, present, and the trend seems to remain valid as far as future predictions are concerned. The agriculture sector is the second-largest contributor to GHG emissions. Emissions from waste and energy production can be significantly reduced through waste to

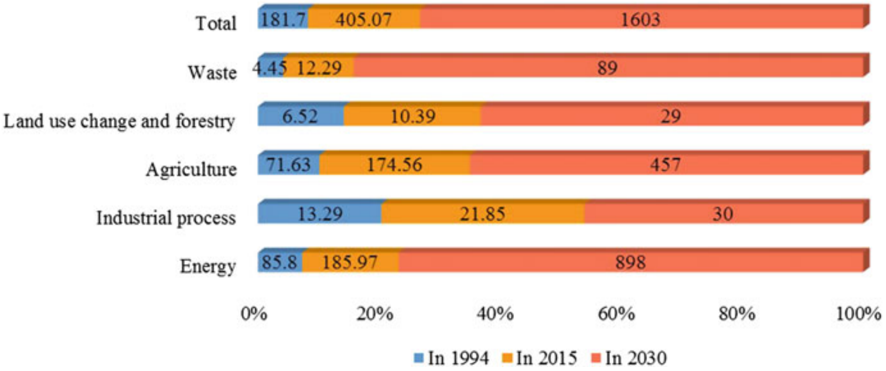

Fig. 2.1 Sector-wise projection of GHG emissions in Pakistan, Mt CO_2-equivalent (source: MPDR-Ministry of Planning Development and Reform 2010)

energy options employing biogas plants. The situation is more promising since Pakistan has all the necessary raw materials for energy production through waste decomposition.

Traditional ways of burning dung cakes, firewood, straw, and agriculture residue with inadequate ventilation systems produce toxic particles and affect human health severely. Indoor air pollution from biomass burning and poor ventilation in homes had increased risk of respiratory infections among children, chronic pulmonary diseases in adults, and other diseases including less birth weight, tuberculosis, ear infection, and cataracts (Bajgain and Shakya 2005). More specifically, 1–2 million deaths were caused because of the burning of solid fuels in Sub-Saharan Africa and have contributed 3–4% of global mortality in 2000 (REN 21 2005).

Developing countries, including Pakistan, are suffering from an energy crisis and ever-increasing gap between energy demand and supply. In order to meet the energy deficit, Pakistan spends around US$7 billion annually on fossil fuels import amounting to 40% of total imports (Heedge and Pandey 2008). The imported fossil fuel is then burnt in various thermal power plants to produce energy. Predictions have shown that energy demands will rise three-folds in 2050; however, the energy supplies do not seem to be increasing proportionately (Asif 2009).

Hence, to meet the ever-growing energy demands and alleviation of the economic situation of Pakistan, and most of the developing countries, the diversified energy mix having alternative energy resources is imperative. In 2010–2011, an economic survey was conducted in Pakistan, and it revealed that biomass is the most readily available and cheapest renewable resource. There is plenty of agri-waste in all rural areas of Pakistan. 652 million kg of animal manure is produced daily by cattle and buffaloes with the potential to generate around 16.3 million m^3 of biogas daily and 21 million tons of bio-fertilizer per year. These biogas energy generation plants can contribute significantly to overcome the energy needs of Pakistan and other developing countries since they require low initial capital cost and can be started with a low budget even on a community level. Biogas plants can serve as good alternative energy for 70% of the population living in rural areas (Korres et al. 2013).

Most pressing issues across the globe such as solid waste management, energy demands, and supply gap, rising methane and CO_2 levels, dependence on fossil fuels, global warming, and life-threatening diseases can be tackled through a single panacea: Biogas production. For instance, if one city is divided into ten blocks or segments and the SWM system of each block is designed individually, then it will allow the concerned departments to manage solid waste effectively. It will not only minimize the consumption of fuel during transportation of solid waste from one block to the last corner of the city, also resulting in traffic congestion and air pollution, but will also provide the concerned block with the valuable resources. Such as, the block can install large-scale biogas plants and hence can become self-sustainable in terms of energy resources. Additionally, it will help improve the solid waste management and reduce the air emissions in general and Carbon emissions emitted during the waste collection and transportation. These kinds of block scaled waste to energy plants when installed on a massive scale, at the national level, can play an instrumental role in addressing global warming, economic crisis, and other environmental crisis of grave concern such as air pollution and solid waste management globally.

Biogas comprises methane 50–70%, carbon dioxide 30–50%, and minor amounts of nitrogen 0–3%, water vapors 5–10%, oxygen 0–1%, hydrogen sulfide 0–10,000 ppm, ammonia, hydrocarbons, and siloxanes. However, the biogas efficiency can be further increased by filtering unwanted gases (Angelidaki et al. 2018). This chapter emphasizes on microbial and biotechnological advancements in biogas production, an evolution of different feedstock choices and operational setups over time. Fixed dome digesters are the earliest form of digesters that were commonly used in developing countries. Floating drum digester is the modified form of fixed dome digester which became operational in 1962. Another form of digester plug flow digester is a cheap digester with a shorter lifespan. Biogas production is initiated and carried out by complex microbial process and a lot of operating conditions affect microbial activity and efficiency such as temperature, oxygen content, pH, substrate, and salt concentration. Different active microbes are required at different stages of biogas production. Biogas is attaining the attention of the public and government because of its feasibility, cost-effectiveness, and market opportunities as an alternate source of renewable energy. European Union is quickly switching to biogas to fulfill growing energy demands sustainably. Malaysia is also promoting small renewable energy programs to gain energy specifically from biomass and municipal waste. Hence, biogas can be, and is, an important means of earning the carbon credits through a reduction in GHGs emissions from conventional solid waste management systems and yielding clean renewable energy instead of employing the fossil fuels' combustion for energy production.

2.2 Biogas

Anaerobic digestion of organic materials produces biogas which is mainly composed of methane and carbon dioxide, with other trace gases such as hydrogen sulfide (McKendry 2002; Hiremath et al. 2009). The process takes place in the absence of oxygen and bacteria degrade organic materials (Incinerators 1977). Biogas composition varies with operating conditions of the digester and nature of the feedstock. The major portion of biogas is composed of 50–75% methane (v/v) and 25–50% carbon dioxide (v/v). Other trace components (v/v) such as water vapor (1–5%), nitrogen (0–5%), ammonia (0–500 ppm) and hydrogen sulfide (0–5000 ppm) are also present (Braun 2007).

2.2.1 Biogas Production Process

Biogas production is a multi-stage and complex process that involves a consortium of bacteria (Fig. 2.2). The followings are the steps involved in the production of biogas.

2.2.1.1 Hydrolysis

In the first step, the complex components of waste or organic matter (carbohydrates, lipids, and proteins) are degraded into simpler compounds (sugars, amino acids, alcohols, and fatty acids) by cellulolytic, lipolytic, and proteolytic bacteria, respectively. Both facultative and obligatory anaerobes such as *Bifidobacterium*, *Megasphaera*, *Sporobacterium*, *Sphingomonas*, *Propionibacterium*, *Lactobacillus* are commonly used in hydrolysis (Khanal 2011).

$$\text{adipic acid} + \text{water} \rightarrow \text{glucose} + \text{hydrogen} \tag{2.1}$$

(Korres et al. 2013)

2.2.1.2 Acidogenesis

Acidogenesis or acid production is the second stage in biogas production. The products of the hydrolysis stage are further broken down in the second step by acidogenic bacteria producing volatile fatty acids (short-chain organic acids), e.g. propionic acid, lactic acid, and butyric acid. Meanwhile, carbon dioxide and methane are also produced. Like hydrolysis, both facultative and obligatory anaerobes such as *Escherichia coli*, *Staphylococcus* spp., *Lactobacillus* spp., *Corynebacterium* spp., *Desulfovibrio* spp., *Bifidobacterium* spp., *Peptococcus anaerobius*, *Clostridium* spp. take part in this phase (Metcalf 2003; Khanal 2011).

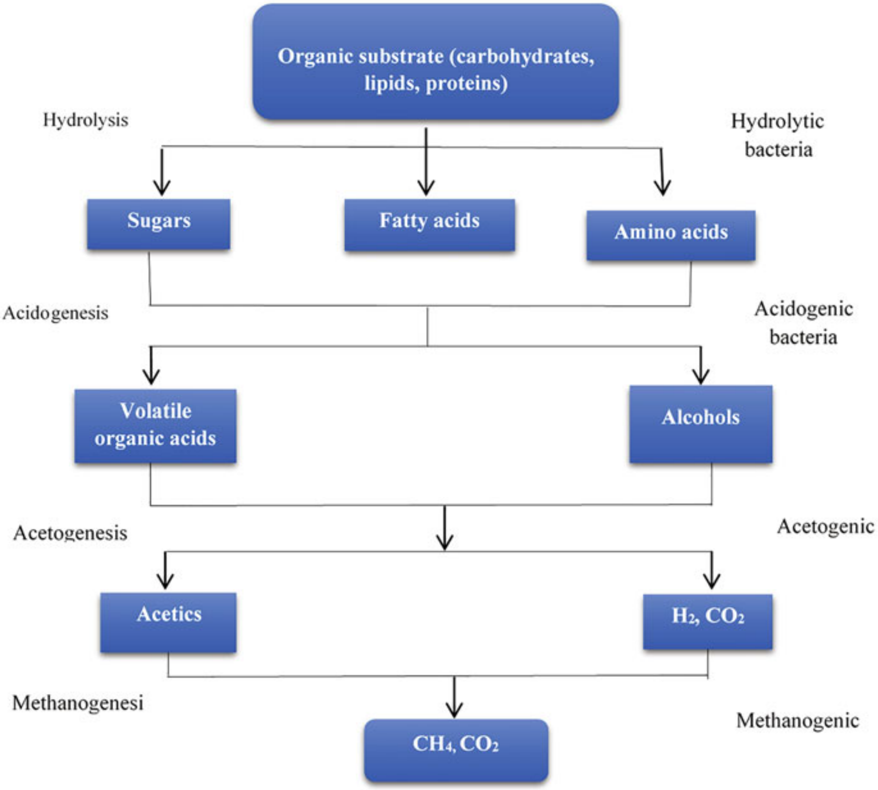

Fig. 2.2 Anaerobic digestion process. Modified from Mao et al. (2015)

$$\text{glucose} \leftrightarrow \text{ethanol} + \text{carbon dioxide} \tag{2.2}$$

$$\text{glucose} + \text{hydrogen} \leftrightarrow \text{propionic acid} + \text{water} \tag{2.3}$$

$$\text{glucose} \rightarrow \text{acetic acid} \tag{2.4}$$

(Korres et al. 2013)

2.2.1.3 Acetogenesis

The third step of biogas production is acetogenesis or acetic acid production. At this phase, acetogenic bacteria breakdown volatile fatty acids and ethanol, produced in acedogenesis (second step), into acetate/acetic acid (CH_3COO^-), carbon dioxide, and hydrogen. Acetic acid, hydrogen, and carbon dioxide are produced by acetogenic bacteria, e.g. *Syntrobacterwolinii* and *Syntrophomonaswolfei* (Vavilin et al. 2008).

$$\text{pripionate} + \text{water} \leftrightarrow \text{acetate} + \text{hydrgen ion} + \text{hydrogen carbonate} + \text{hydrogen} \tag{2.5}$$

$$\text{glucose} + \text{water} \leftrightarrow \text{acetic acid} + \text{carbon dioxide} + \text{water} \tag{2.6}$$

$$\text{glucose} + \text{water} \leftrightarrow \text{acetic acid} + \text{carbon dioxide} + \text{hydrogen} \tag{2.7}$$

(Korres et al. 2013)

2.2.1.4 Methanogenesis

The fourth and last stage involves the transformation of CO_2, H_2, and acetate into a blend of CH_4 and CO_2 through acetotrophic and hydrogenotrophic methanogens. Acetotrophic methanogenesis is the process in which acetotrophic methanogens use acetate as a substrate. Hydrogenotrophic methanogenesis is the utilization of the H_2 as an electron donor to reduce the CO_2 by hydrogenotrophic methanogens. Bacteria from the genera *Methanosaeta*, *Methanosarcina*, *Methanobacterium formicidcum*, and *Methanobacterium ruminantium* are involved at this stage (Alexander 1978).

$$\text{carbon dioxide} + \text{hydrogen} \rightarrow \text{methane} + \text{water} \tag{2.8}$$

$$\text{acetic acid} \rightarrow \text{methane} + \text{carbon dioxide} \tag{2.9}$$

$$\text{ethanol} + \text{carbon dioxide} \rightarrow \text{methane} + \text{acetic acid} \tag{2.10}$$

(Korres et al. 2013)

2.2.2 History

Before the birth of Christ, renewable resources, e.g. wastewater was used for the energy supply, e.g. combustible gas was used to heat water by the Persians and Assyrians (He 2010). The Sumerians around 3000 BC practiced anaerobic cleansing of waste. Pliny, the Roman scholar, explained the flickering lights which appeared under the surface of swamps (Deublein and Steinhauser 2011). In 1804, the chemical composition of inflammable air was identified to be CH_4 by Dalton. The first scientist to produce biogas was Gayon (Tietjen 1975). More scientific and systematic research to understand and comprehend the process of anaerobic fermentation kicked start in the nineteenth century (Deublein and Steinhauser 2011). However, in the nineteenth century, the risk of failure was higher and anaerobic digesters were smaller in capacity. The technology of anaerobic digestion moved from laboratory experiments to field applications. In France, the simple air-tight chamber was used to treat sewage. In England, the septic tank was used to treat wastewater (McCarty 2001; Gijzen 2002). In Exeter, street lamps were run on gas produced from wastewater (Fig. 2.3). Germany first sold methane to the public in 1923. Using biogas was very popular until the Second World War. During the period 1930–1940, biogas was produced using agricultural waste. The importance of biogas was reduced around

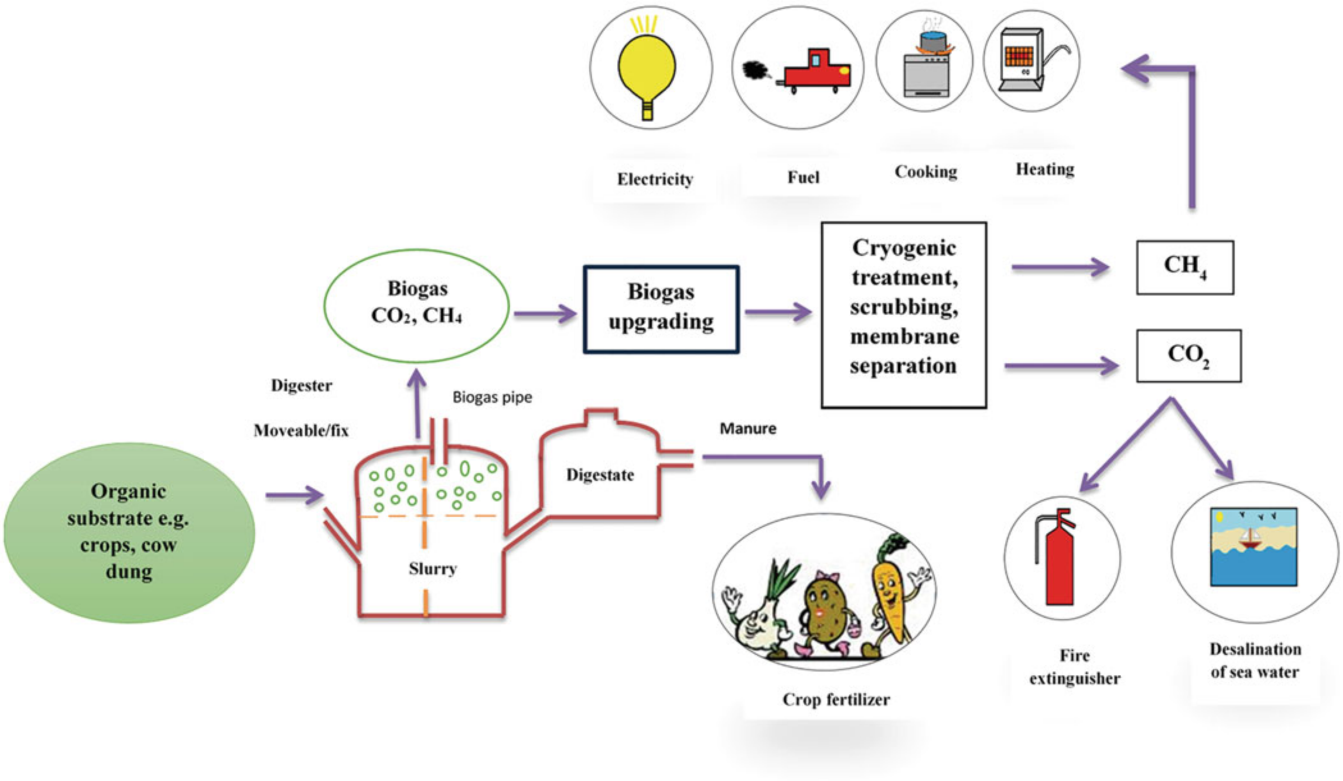

Fig. 2.3 Schematic diagram of biogas production and utilization

1955 due to the excessive availability of oil. In the 1990s, profitability and prevention of waste production, pollution prevention, were reasons for the stimulation of biogas technology (Deublein and Steinhauser 2011). In the twentieth century, Germans invented "Imhoff digesters" for sewage sludge treatment. Using the same technology, larger anaerobic digesters were used for the treatment of sewage sludge for public national gas grid in 1920 (Bond and Templeton 2011).

2.2.3 Types of Digesters

2.2.3.1 Fixed Dome Digesters

Fixed dome digesters are being operated in China since the early twentieth century and commonly used in developing countries: Ghana, Kenya, and India (Akinbami et al. 2001; Chen et al. 2008; Bond and Templeton 2011; Nzila et al. 2012). They are also called "Hydraulic" or "Chinese" digesters (Santerre and Smith 1982). Clay, concrete, and cement are used for the inner walls of the digester to make it impermeable (Chen et al. 2008). An inlet pipe is used to fill the digester chamber and biogas is collected in the storage section. Due to the height difference between the expansion chamber and slurry in the digester, gas pressure is produced. Some substrate is introduced into the expansion chamber as the produced gas requires space and presses it. A digester is immediately filled again with slurry as the gas releases (Sasse et al. 1991). They are built underground (Santerre and Smith 1982) and thus, require skilled labor incurring higher costs (Veen et al. 2009). Another cost factor is the transportation of construction materials in case biogas plants are constructed in remote areas (Pérez et al. 2014). The main advantage of this model lies in its low maintenance costs as it is immovable, and the absence of metallic parts makes it immune to rusting. This model does not produce gas at constant volume and the pressure of the gas is not maintained, thus less inefficient to run a gas generator, and gas heater. The construction material is prone to crack, which leads to digester failures. The lifespan is over three years for these types of digesters (Cheng et al. 2014).

2.2.3.2 Floating Drum Digesters

This digester was built in 1962 and its original name was Khadi and Village Industries Commission (KVIC). This model is widely used in India (Rajendran et al. 2012). Like fixed dome reactors, these digesters are also constructed underground using steel and concrete. The digester is cylindrical and there is a moveable inverted drum for the collection of gas, which is made of PVC or steel. The drum moves upward as the gas is produced and falls back as the gas is drawn off. (Singh and Sooch 2004; Rajendran et al. 2012). There are no mechanisms for heating or mixing in these digesters (Cheng et al. 2014; Surendra et al. 2014). This model has an advantage of the production of the gas at constant volumes, as the drum maintains it. Moreover, stored gas volume can be determined easily, and the overall digester's operations are simple. However, the downsides affiliated with this type of digester are its high construction costs due to expensive raw materials (steel). Since steel is prone to corrosion, so it needs regular maintenance and monitoring. All these factors contribute to a lifespan of 8 years. Furthermore, presence of any fibrous material hinders the movement of the drum (Rajendran et al. 2012). Because of inefficient agitation, deposition of solids occurs restraining the exposure of the substrate to microorganisms (Singh et al. 1997).

2.2.3.3 Plug Flow Digesters

In 1957, South Africa used this type of digester design for the first time (Ghosh and Bhattacherjee 2013). High-density polyethylene is used for construction (Lansing et al. 2008). This model consists of a narrow and long tank. The inlet and outlet are located opposite to each other. The parts above ground are inlet and outlet, while other parts are kept in an inclined position underground. The two processes, acidogenesis and methanogenesis are separated due to the inclined position creating a two-phase system. The digestate flows at the other end as a new substrate is added through the inlet. A shed roof or gable is used to cover the digester to avoid temperature fluctuations and provide insulation (An et al. 1997; Bouallagui et al. 2003; Ferrer et al. 2009, 2011). The comparatively lesser lifespan makes it economically less viable. The shorter lifespan is because of the fragile nature of PVC which is subjected to extreme conditions and forceful mechanical contact (Nzila et al. 2012). This model has the advantage of simple design, adaptability to extreme conditions, easy handling, easy installation, reasonable retention time, and low capital cost (Ghosh and Bhattacherjee 2013). There are no moving parts so failure risks are reduced (Singh et al. 1997). However, certain disadvantages such as less biogas production, the slow solid conversion, and absence of agitation are also associated with this model (Ghosh and Bhattacherjee 2013).

2.3 Range of Waste Utilization in Biogas Production

A diverse range of waste types can be utilized for waste to energy technologies like anaerobic digestion (AD). Different types of organic waste include food waste, animal dung or livestock manure, agricultural waste, sewage sludge, industrial waste, and the organic portion of municipal solid waste (Khalil et al. 2019). These waste types can be very harmful to the environment and human beings when openly dumped (Raheem et al. 2016). Table 2.1 compares the biogas production from different types of waste, digester and energy potential (Fig. 2.4).

The biogas generation potential of cattle dung varies from 56 to 68 m^3, fats biogas potential varies from 826 to 1200 m^3, and that of pig slurry varies from 11 to 25 m^3. The biogas yield and electricity generation of every waste is given per ton of fresh matter (Achinas et al. 2017).

Table 2.1 Comparison of different types of digesters (source: Korres et al. 2013)

Classification basis	Substrate feeding		Substrate DS content		AD process technology	
Types	Batch digester	Continuous digester	Dry digester	Wet digester	Single stage	Two stage
Advantages	No need for pumping, mixing, stirring	Capital cost is low, design and operation are simple	Simpler pre-treatment, retention of biomass is higher	Freshwater dilutes inhibitors	Less technical failure, simple design	Recirculation increases degradation Less susceptible to failure
Disadvantages	Biogas yield is low, clogging and channeling	Production of larger VFAs and acidification	Expensive, complex, mixing and material handling is difficult	Crop digestion leads to scum formation, risk of short-circuiting	Retention time is high, formation of scum and foam	Construction and maintenance are expensive, solid particles need to be removed

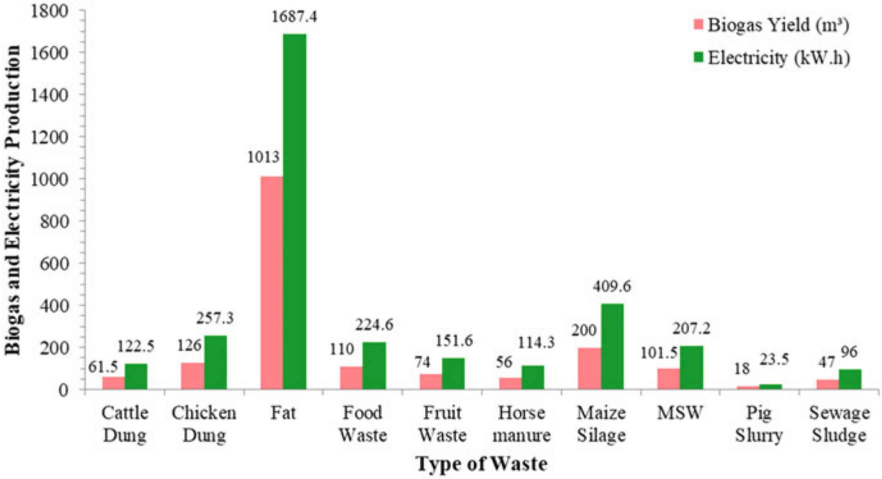

Fig. 2.4 Biogas yield and electricity production potential of different feedstocks (source: Achinas et al. 2017)

2.3.1 Animal Dung

Animal dung holds a significant amount of nitrogen and phosphorus. The high concentration of these elements disturbs the nutrient cycle and degrades the environment. It comprises some other harmful residues like heavy metals, hormones, antibiotics, and microbes, which not only pollute the environment but also become the sources of hazardous human diseases. This is one of the leading causes of air, water, and soil contamination. Therefore, the conversion of livestock waste to useable energy form, i.e. biogas is the most environmentally friendly and sustainable means of its utilization (Abdeshahian et al. 2016). In Asian countries, the most common sources of animal dung are poultry, cattle, sheep, goats, horses, camels, and buffaloes, and their number is also growing day by day. The amount of manure, an animal excretes, is directly linked to its age, weight, and feeding behavior. Total waste can be estimated by multiplying waste excreted (by an animal in a year) with a total number of animals. The poultry sector is the chief sector in all the Asian countries like India, Pakistan, Bangladesh, Nepal, and Sri Lanka with 656, 530, 242, 24, and 15 million birds, respectively, produced per annum. The dung produced per animal in the poultry sector is 0.05 tons annually. On the other hand, manure produced by a buffalo and a cow is 6.1 and 6.0 tons per year, respectively. Their headcount is 30 million buffaloes and 31.8 million cattle in Pakistan, whereas 98.6 million buffaloes and 174 million cattle in India. Therefore, the poultry birds may be high but waste excretion is most elevated in the case of buffaloes and cows that are noteworthy in biogas generation (Raheem et al. 2016). Poultry waste contains dry organic matter, feathers, head, feet, offal, and blood that are carbohydrates, proteins, and lipids. Manure is composed of 35% dry material, 24% protein, and 18% fats. As poultry waste is produced in a large amount, about 97.5 × 10^6 cubic meter of biogas can be produced by utilizing all poultry waste in an AD process (Arshad et al. 2018).

2.3.2 Agriculture Residues

Agricultural crop residues are one of the essential sources of biofuel energy. It contains woody substances, crops remain, and fruits and vegetable residues. Crop residues can be gathered from two sites: first in the agricultural field where crops are grown and harvested, and second from the factories or industries where crops are processed. The residues collected from the field include leaves, twigs, seeds, and straw, whereas those obtained from processing sites include bagasse, roots, and husk, etc. Crops like wheat, rice, corn, sugarcane, and cotton produce large quantities of residues beneficial for biogas generation. Other than croplands, processing factories produce fruits and vegetable wastes and their derivatives, which are equally important. Asia accounts for 61% of the vegetable production worldwide, i.e. largest source. About 30% of the global fruit supply comes from India, Brazil, and China. Industries, from all over the world, produce large quantities of these wastes including 81 million tonnes of potatoes, 37 million tonnes of tomatoes, 29 million tonnes of citrus, 25 million tonnes of bananas, 17 million tonnes of apples and grapes (Paudel et al. 2017). Grassland is also getting attention because of its beneficiary use in biogas production. Grass silage has a high number of volatile solids which is directly proportional to biogas yield. About 300 m^3 of methane can be generated by using one ton of volatile solid (Nizami et al. 2009).

Typically, agricultural straw has a low nitrogen content and they are lignocellulosic, which make them difficult to digest in the process of biogas generation. Their complex structure is the main limitation of ineffective processing. To prevent this problem, several researches have suggested pre-treatment methods (Onthong and Juntarachat 2017). De-lignification treatment is a suggested method to break down the complicated polymer structures of agricultural and forest wastes. It can be carried out through several chemicals, mechanical, biological, thermal, and combined approaches as well (Yu et al. 2019).

2.3.3 Municipal Solid Waste

Municipal solid waste (MSW) is continuously increasing with a rapidly growing population globally. It is estimated that the annual production of MSW will grow to nearly 27 billion tons per year until the year 2050 (Ali et al. 2019). The organic portion of MSW is approximately 46%, comprising food waste, kitchen waste, and garden waste. Other than an organic fraction, paper waste makes up about 17%, plastic waste 10%, glass and metals 9%, and others 18%. One ton of organic portion of MSW can produce around 200 m^3 of biogas which can generate 400 kWh of electricity (Tyagi et al. 2018). Food waste is a major portion of this organic waste. It has a high carbon-nitrogen ratio as well as volatile solids and total solids ratio.

According to USEPA, 1000 kg of food waste have the potential of producing 376 m^3 of biogas (Ali et al. 2019). The highest food waste generation rate is 0.5 kg per capita per day in Canada, then 0.37 and 0.3 kg per capita per day in England and the United States, respectively. In developing countries, India, China, and Brazil have the maximum food waste generation rates (Dung et al. 2014).

2.3.4 Co-digestion of Multiple Wastes

The efficiency of anaerobic digesters can be increased by using more than one waste type in a single digester, also known as co-digestion. It is reported that up to 43% methane production can be improved because of the synergetic effects (Horváth et al. 2016). In Germany, grass and maize silage are commonly digested together in biogas plants (Nizami et al. 2009). Co-digestion of poultry waste and rice husk is also suggested to produce energy and considered being cost beneficent and environmentally sustainable procedure (Arshad et al. 2018). About 220 kg of rice husk can be produced from one ton of rice paddy, and its potential of producing energy can be estimated from the fact that one ton of rice husk can generate up to 570 kWh electricity (Ali et al. 2016). Agricultural residues combined with livestock waste and food waste is also a very promising co-digestion strategy to enhance environmentally friendly biogas generation (Hagos et al. 2017).

2.4 Microbial and Biological Advancement

A complex microbial process is responsible for efficient biogas generation through the action of numerous microbial species utilizing different substrates as feedstock. These organisms need to work collectively to attain maximum output. Thus, a simple principle is to introduce anaerobic microorganisms for the degradation of the organic material which is kept in an air-tight container for ensuring that no oxygen enters it (Schnürer and Jarvis 2018).

2.4.1 Environmental Influences

These microorganisms require an appropriate environment for multiplication and accomplishment of their function. Some significant ecological aspects of development are:

- Temperature
- O_2 concentration
- pH
- Salt content

Varieties of microbes require varied suitable environmental factors central to their optimum growth. It briefly describes some of these factors below:

2.4.1.1 Temperature

The maximum temperature variation depends on the adapted temperature range of the microorganism. Biogas production involves diverse microorganisms, and they have variable optimum temperatures, that is why their responses also vary to some extent. The biogas process typically runs at a temperature range of about 30–40 °C or 50–60 °C. Biogas generation can also take place at psychrophilic temperatures but might lead to a reduced CH_4 production rate depending on the type of process (Bohn et al. 2007; McKeown et al. 2009; Dhaked et al. 2010). At elevated temperatures, there are examples of methanogens that can survive at up to 110 °C (Chaban et al. 2006), whereas stable biogas production mechanisms do not appear to function above 60–70 °C (Scherer et al. 2000). In case of a temperature higher than 60 °C, the activity of methanogens is greatly decreased compared to acid producers, which usually leads to the fatty acids' buildup in the biogas process (Scherer et al. 2000). Thermophilic organisms endure high temperatures (up to 60 °C approx.) although their maximum growth occurs at the mesophilic temperatures.

2.4.1.2 Oxygen Concentration

The importance of oxygen concentration is variable for the diverse microbial communities involved in the production of biogas. Microorganisms are generally divided into several groups in relation to their suitable oxygen content requirement (Fig. 2.5).

2.4.1.3 pH

Different microorganisms involved in the generation of biogas correspond significantly differently to a range of suitable pH for their optimum multiplication and development (Table 2.2).

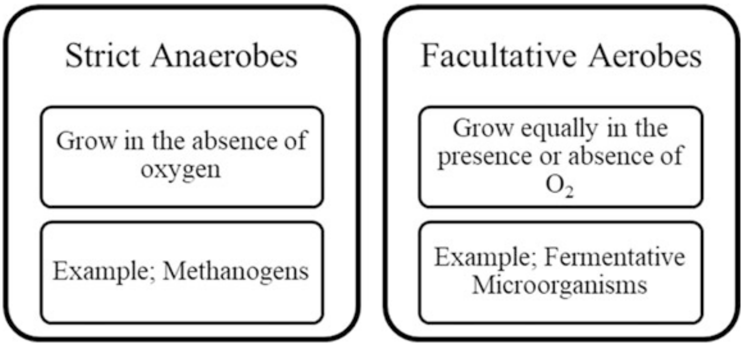

Fig. 2.5 Classification of microbes involved in biogas process based on oxygen content (Ağdağ and Sponza 2004)

Table 2.2 Suitable pH values for microorganisms involved in the biogas process

pH requirement	Microorganisms	pH value
Low pH/acidic conditions	Fermentative and acid-forming microorganisms, acidophilic methanogens	5 or less than 5
High pH/alkaline conditions	Alkaliphilic methanogens	10 or greater than 10
Neutral pH	Methanogens	7

Although the growth of most methanogens occurs at pH of around 7, neutral, these may also survive at other pH environments as well (Whitman et al. 2006). Some well-acknowledged microbial strains such as acid-loving methanogens grow at pH less than 5—around 4.7 (Bräuer et al. 2006) and alkali-loving methanogens whose growth occurs around pH 10 (Mathrani et al. 1988). In Sweden, many biogas production methods are operational at pH around 8. In addition, research writings likewise encompass illustrations of biogas production approaches functioning at less than 6 pH (Savant et al. 2002).

2.4.1.4 Salts

All microorganisms need salts for proper functioning. Salts comprise essential building blocks, i.e. Na, K, and Cl; for the microbes. These substances are naturally available in most substrates, and their separate addition in the biogas process is not needed. Salts usually have an antibacterial behavior and act as inhibitors for the growth of bacteria. Methanogens are greatly influenced by the high salt content involved in the biogas generation (Chen et al. 2008).

2.4.2 Substrates

Carbon-based waste is utilized to produce biogas and accounts for several substrates for different microbes. The greater the types of components in the waste used, the higher the availability to a variety of microbes for biogas production is. Substrate composition is significant both for the output gas produced and the qualitative aspects of it.

2.4.2.1 Substrate-Specific Enzymes and Microbial Strains

Enzymes are usually substrate-specific, and the microbial strains that provide these enzymes are also particular (Fig. 2.6). Biogas process involves several types of substrates as raw materials for the generation of biogas, using several microorganisms that are responsible for providing enzymes specific to substrates. The flow diagrams below illustrate the different kinds of raw materials utilized as substrates by several enzymes that act upon them for attaining the desired biogas products. These different substrate types have a different chemical composition and require specific microorganisms that offer enzymes needed for their degradation and formation of new products.

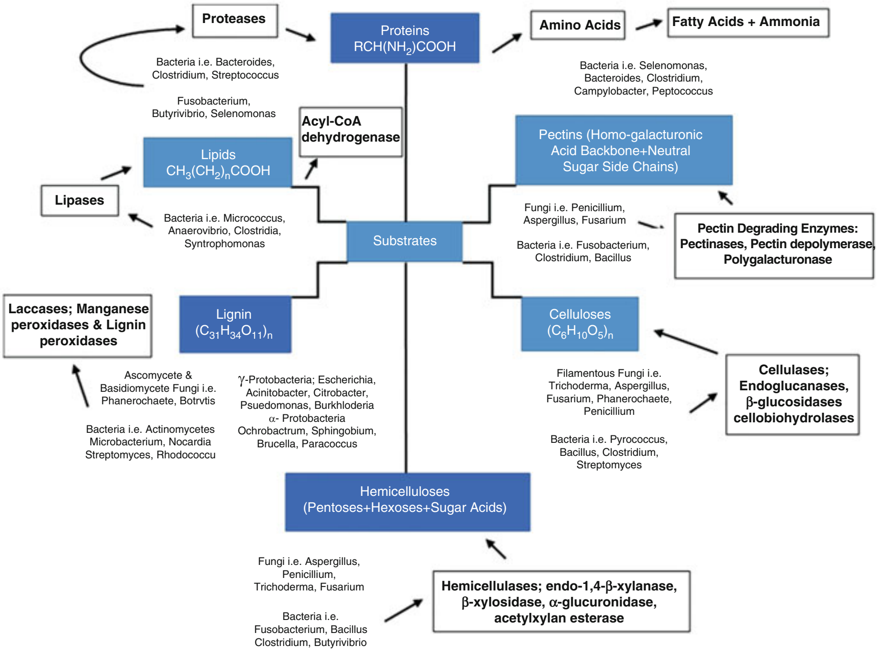

Fig. 2.6 Different substrates, their chemical composition and Microbial strains that produce specific enzymes for the substrate degradation

As described in the diagram above, every substrate gets converted into a unique bio-product by the action of enzyme groups released by various specific microbial strains. The table given below gives an insight into a series of different substrate groups along with their chemical composition, including the amount of carbon and nitrogen contents. Several various sources of these substrates are also shown, i.e. various industries (pulp, paper, and food), wastage, and some other materials. Substrates require optimum temperatures for their degradation because of their enzyme and microbe specific nature; that is why the temperature requirements of each of the substrate groups listed in the Table 2.3 are clearly mentioned.

2.4.3 Active Microorganisms at Different Stages of Biogas Process

The existence of numerous diverse microbiological species is vital for the functioning of the biogas generation process and for producing end products: methane/hydrogen gas. All the microbes involved in action need to work similarly collectively (Angelidaki et al. 2011; Schnürer et al. 2016).

The microbial strains that are dynamically involved in the entire process are illustrated as Fig. 2.7.

Table 2.3 Different substrates used in the production of biogas along with their composition, sources, and temperature requirements

Substrates employed for biogas production		Composition	Sources	Temperature requirement	References
Food waste and waste from food industries		Proteins, fats, carbohydrates, and various trace elements	Food industries and restaurants	Mesophilic and thermophilic	Gunaseelan (1997), Capson-Tojo et al. (2016), Zhang et al. (2016)
Manure	*Solid Manure*	Highly carbon enriched with greater dry solids amount up to 70%. Straw + hay + feces	Cattle yields, pigs, horse, and poultry	Mesophilic	Nasir et al. (2012), Hadin and Eriksson (2016)
	Liquid Manure	Greater nitrogen content along with a lesser number of dry solids up to 10%.			
Crops and crop residues		Dry solid amount approx. 10% to 50%. Cellulose + hemicellulose + lignin (e.g. straw)	Potatoes, corn, silage, sugar beets, grass, grain, fruit, straw, foliage	Self-heating of the process, i.e. Planned process temperature of 35–39 °C, increased to 42–49 °C with temperature increase of 0.15–0.5 °C/day	Braun et al. (2008), Lindorfer et al. (2008)
Waste from slaughterhouses and fisheries		Fats and proteins/high C/N ratio	Blood, guts/colon or soft tissue, fish wastes, wastewater	Mesophilic and thermophilic	Salminen and Rintala (2002), Franke-Whittle and Insam (2013), Bustillo-Lecompte and Mehrvar (2015), Hamawand (2015)
Sewage sludge		Populations of aerobic microorganisms with cell walls of complex proteins and carbohydrates	Sewage waste	Thermophilic	Anjum et al. (2016), Demirbas et al. (2016)
Algae	*Macro-algae*	Dry solids content about 10–15%, low lignin content, 20–70% fat depending upon growth conditions	Food, fat-accumulating species of algae and EPS	Co-digestion under mesophilic + thermophilic settings	Chen et al. (2015), Zhang et al. (2016)
	Micro-algae				

Wastewater and Sludge from Pulp and Paper Industries	Some soluble organic material and various potentially inhibiting organic substances, i.e. bleaches (peroxides), chlorinated compounds, sulfur compounds (sulfate, sulfite, etc.) tannins, terpenes, and LCFA	Pulp and paper industry	Mesophilic	Meyer and Edwards (2014), Kamali et al. (2016), Zhang et al. (2016)
Stillage	Rich in protein, also releases furfurals, small phenolic compounds	Ethanol production, untreated waste, wheat, and other crops or cellulose-rich residues	Mesophilic	Torry-Smith et al. (2003), Jönsson and Martín (2016)
Wood products	High carbon content and releases phenolic compounds	Untreated spruce and pine, Salix and poplar	Thermophilic	Ericsson et al. (2014)

Sources: Van Soest et al. (1991), Saha (2000), Brummell (2006), and Kumar et al. (2008)

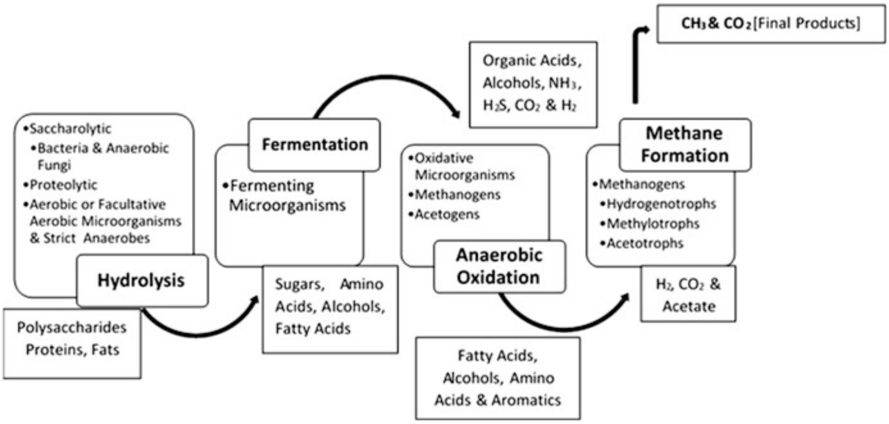

Fig. 2.7 Active microorganisms at different stages of the biogas process described stepwise (Schnürer and Jarvis 2018)

The flow diagram above is an illustration of the whole biogas process, with each step distinguished from the other. The kinds of microbes involved in each stage are shown along with the substrate compounds that, after degradation, change their form and get converted into smaller molecular constituents. The microbial strains involved are also sensitive to the type of molecule or compound of the given substrate material. In the biogas production, the action of microbial groups is limited to a specific stage of the process.

2.4.3.1 The Methanogenesis Pathways

Methanogens are classified depending on the type of substrates utilized by them, i.e. either hydrogenotrophs, methylotrophs, or acetotrophs. Similarly, different biochemical pathways are used by each type to produce methane (Korres et al. 2013), depicted as Fig. 2.8.

The two pathways shown above depict that the products formed depend on the type of microorganism. The acetotrophic methanogens directly convert into the desired product biogas, and carbon dioxide is produced as a byproduct. Whereas in the second pathway shown above, the two microbial types represented first convert acetate to hydrogen gas and carbon dioxide, and afterward, it is obtained as biogas in the second step.

2.4.4 Evolution of Microorganisms

The great diversity of microbial species offers the opportunity to discover innovative metabolic functions in recently discovered strains and to explore for enzymes of specific, identified function via screening for genes coding of such enzymes (Krause et al. 2006; Simon and Daniel 2009; Uchiyama and Miyazaki 2009; Dugat-Bony et al. 2012). Two common domains in the biogas microbial communities are bacteria

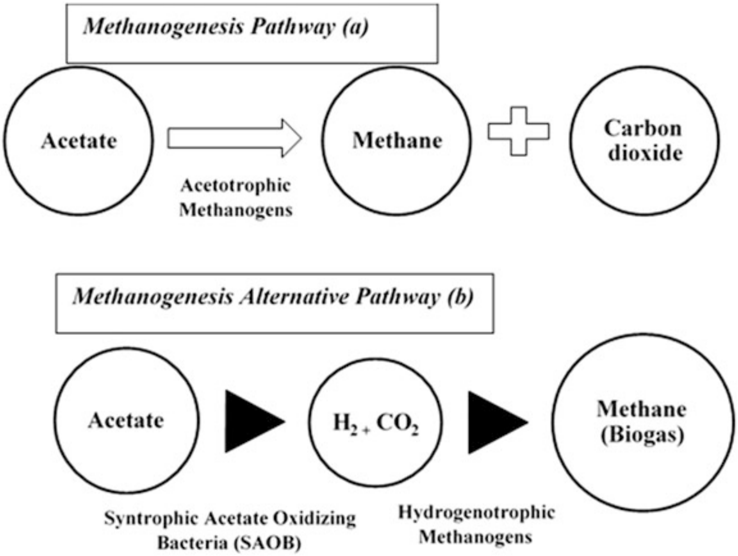

Fig. 2.8 Different biochemical pathways for methane production

and archaea counting methanogens. Eukaryotes, i.e. anaerobic fungi, along with viruses, have also been discovered. Representatives of the bacterial phyla, i.e. *Firmicutes* and *Bacteroidetes* are dominant in the production of biogas. However, members of the phyla *Chloroflexi* and *Proteobacteria* are likewise identified in the process, though less abundant (Schnürer et al. 2016). Methanogens found in the biogas process belong to phylum *Euryarchaeota*, whereas fungi identified belong to *Neocallimastigomycota*. Some microorganisms existing are still not being identified as of today.

Usually, microorganisms that can be typically seen in the AD process comprise *Clostridium* spp., *Actinomyces*, *Escherichia coli*, *Micrococcus* spp., *Peptococcus anaerobius*, *Desulfovibrio* spp., *Lactobacillus*, *Bifidobacterium* spp., *Staphylococcus* spp., *Corynebacterium* spp., *Bacillus* spp., *Methanospirillum, Methanobacterium*, *Methanosarcina*, *Methanobacillus*, *Methanothrix Methanococcus*, and *Methanosaeta* (Grangeiro et al. 2019).

2.4.5 Biofuel Generations

There are a few biofuel generations that have been developed over time based on the substrate material being utilized. The first generation of biofuel was formed by employing starch, edible oil, and sugars; then comes the second generation of biofuels that being contrarily generated by utilizing non-edible biomass; next, third biofuel generation is formed by using algae; whereas fourth biofuel generational group is formed by the capturing of CO_2 or by employing certain other innovative technological advances. However, presently produced biofuel contains a significant proportion of first generational groups (Bhatia et al. 2017).

2.4.6 Microbial Advancement in Production of Biogas (Biohydrogen)

Various microorganisms have been stated as beneficial to produce biohydrogen. Commercial production of biohydrogen for economic wellbeing requires the consumption of lignocellulose. Jiang along with his coworkers utilized acid hydrolyzed sugarcane bagasse as a raw material for the fermentation of *Clostridium butyricum* and reported 2.06 mol H_2/mole-total sugar. To overcome the problem of temperature variances between saccharification and fermentation, in a complex process consuming lignocellulose, a thermophilic strain was isolated by researchers, i.e. *Thermoanaerobacterium thermosaccharolyticum* for carrying out fermentation at higher temperatures and reported 6.38 mmol H_2/g. *Clostridium thermocellum* is also capable of performing biohydrogen fermentation at high temperature but its productivity is low. Then, Wang and his coworkers employed a coculture of *Clostridium acetobutylicum X9* in addition to *Ethanoigenens harbinense B49* for hydrogen generation consuming cellulose as a carbon source, and 8.1 mmole H_2/g was reported. For enhancing the efficiency of biohydrogen production, Cha with his coworkers engineered *Caldicellulosiruptor bescii* by removing lactate dehydrogenase, and the resultant strain was capable of producing 21–34% more hydrogen (Bhatia et al. 2017).

2.4.7 Enhancing the Efficiency of Biogas Process

Some ways of improving the yield of biogas process are stated as follows:

2.4.7.1 Bio-augmentation

Lately, various efforts have been made for improving the biogas production by direct addition of microbes or enzymes, with some success (Schnürer et al. 2016). This bio-augmentation has been brought into light chiefly for improvement in the hydrolytic step and enhancement in the degradation of lignocellulose. For instance, the degradation productivity of a substrate, i.e. wheat straw was augmented with the addition of cellulose-degrading bacterium *Clostridium cellulolyticum*.

2.4.7.2 Addition of Microorganisms

Naturally, present microorganisms or artificially prepared ones could also be cultured collectively, for the advancement of some actions, i.e. rise in the consumption range of substrate, enhance the yield, and enable the reclamation procedure (Bhatia et al. 2017). Improvement in the stable and efficient production of CH_4 at elevated NH_3 contents is also attempted, and for this purpose adding the methanogen. *Methanoculleus bourgensis* resulted in increased methane production and a stable process. A greater CH_4 output was also achieved by subsequently adding H_2 producer organism, i.e. acetogenic *Enterobacter cloacae*, whereas a quicker degradation of fat was attained after adding *Clostridium lundense*.

2.5 Opportunities

The development and expansion of non-fossilized clean energy source are of significance to the energy security and environmental integrity (Bong et al. 2017). The considerable development in the manufacturing of goods is relieved by the worldwide population increase and advancement in technology, hence leading to an exponential rise in the economy of the industrialized nations. It should also be considered that all the raw materials and fuels, which are extracted from the earth, convert into emissions or waste at some point. The aim should be to keep the volume of these emissions as low as possible, which ultimately would reduce the negative impact on the environment (Barik 2018). There is an increasing concern over the high production rate of organic waste due to rapid urbanization and population growth around the globe. Biogas is of great interest among the renewable energy available due to its ability to treat organic waste and generate power addressing both concerns at the same time.

Production of biogas using the animal manure produced in farms represents an additional energy source for generating heat and electricity (Ramos-Suárez et al. 2019). Thus, it is not wrong to say that biogas is a plethora of opportunities in the case of both, meeting demands contrast to the energy crisis and a solution to the immense waste disposal problem.

2.5.1 Factual Productivity Through Biogas

Biogas production, utilization, and renewable energy, cost-effectiveness, business and commercial potential, and market principles are emphasized as a standard criterion for renewable energy technologies in economic arguments and various policy documents. Biogas occurs as a major part of it (Table 2.4).

Considering a net amount of waste to be 2.12 billion metric tons per year (as stated by the reports of World Bank 2018) we surely have a huge amount of waste to be generated every year (Levine 2018). This amount is contributed as 0.74 (kg) of footprint per person per day. Almost 70% of the net amount of waste is organic in kilograms nature, which makes up to 1.484 billion metric tons of waste (Gautam et al. 2019). Out of the 70% organic waste (The World Bank), the expected biogas production mainly depends on the contents of both dry matter (DM) and lignin (% of DM) of the organic waste (research gate). So, rounding off, we can conclude that almost 60% of organic waste can be utilized for biogas production. Ending up, we have nearly 1.3 billion tons of waste feasible to produce biogas. Considering 100% of organic waste produces 153 m^3 ton-1 (Al-Addous et al. 2019), 60% of organic waste will end up in 91.8 m^3 ton-1 production of biogas. 1.3 billion tons of 60% organic waste would be ending up in 119.71 billion m^3 of biogas. The

Table 2.4 Energy consumption

Constituent	Usage in 2016 (in million tons of oil equivalent)	%Annual increase/decrease from 2005 to 2016
Total amount of energy	13,276	1.8
Natural gas	3204	2.3
Oil	4418	1.1
Nuclear electricity	592	−0.5
Coal	3732	1.6
Hydroelectricity	910	3.0
Wind and solar electricity	292	25.3
Biomass, geothermal, and other renewable electricity	127	7.4

Source: Gautam et al. (2019)

LCA to be carried where we have 1 m^3 of biogas corresponds to 6.29 barrels of oil. The cost of one barrel of oil is equal to 53.76 USD. So, the 119.71 billion m^3 of biogas produced is equivalent to 753 billion barrels of oil and the cost is 39,909 billion USD approximately. This gives us a scenario about the financial benefit of production of such amount of biogas.

2.5.1.1 European Union and Europe

Biogas production has seen an unremarkable growth in last years around Europe (Table 2.5). It was mainly driven by favorable support schemes in various European Union Member States.

The rate of production of biogas has improved in the European Union. An increase in biogas production is also associated with renewable energy policies, environmental, social, and financial benefits, and it reached 18 billion m^3 methane (654 PJ) in 2015, which represents half of the global biogas production (Scarlat et al. 2018).

2.5.1.2 Malaysia

Malaysia has been continuously inferring Renewable Energy-promoting policies and actions, for instance, the Small Renewable Energy Program, National Green Policy 2009, National Renewable Energy Act 011, Feed-in Tariff (FiT) mechanisms, Renewable Energy business fund, and Green Technology Financial Schemes.

Precisely, the Renewable Energy resources included energy from biomass, municipal waste, and biogas. Biogas is relatively essential in a waste management perspective as it can offer a win–win scenario towards the nation's efforts to achieve energy security along with combating waste accumulation. Biogas is one of the useful end products of the anaerobic digestion processes of organic waste where it is utilized to generate electricity. The most crucial and vital source for the generation of biogas in Malaysia is palm oil effluent (POME), livestock manure, and MSW (Ali et al. 2012; Mekhilef et al. 2014). The potential of electricity produced by the biogas is estimated to be 100 megawatts (MW) by 2015 (Shafie et al. 2011) with an energy reservoir of 410 MW by 2030 and of 360–400 MW by 2020 (Khor and Lalchand

Table 2.5 Production of biogas in Europe in 2015

European countries	Production of biogas mil m^3
Belgium	264
Bulgaria	23
Czech Republic	715
Denmark	177
Germany	9160
Estonia	15
Ireland	64
Greece	107
Spain	305
France	628
Croatia	42
Italy	2183
Cyprus	13
Latvia	102
Lithuania	27
Luxembourg	21
Hungary	93
Malta	2
Netherlands	381
Austria	350
Poland	267
Portugal	96
Romania	21
Slovenia	35
Slovakia	173
Finland	120
Sweden	195
UK	2627
Switzerland	128
Iceland	2
Norway	52
FYROM	6
Servia	7
Moldova	11
Ukraine	17
EU	18,207
Europe	18,429

Source: Scarlat et al. (2018)

2014). But as the Malaysia Sustainable Energy Development Authority (SEDA) stated to date, the cumulative installed capacity for biogas is only 6.48 MW and 6.36 MW (from landfill/agricultural waste) by 2015. Still, there is high Renewable

Energy potential from biogas, which could be garnered from MSW and this could be accomplished in a better way if there are more supporting policies (Bong et al. 2017).

2.5.1.3 Canary Islands

Biogas production from the animal manure in the farms of Canary Islands represents an additional energy source for heat and electricity production. 495.622 tons of manure per year is produced from all the farms on the island. Processing this manure for biogas production results in the overall 27.1 Mm^3 biogas potential per year with a comparable installed capacity of 6.8 MWe. If we consider 0.5 tons of manure production per day (the lowest limit for implementing biogas project), 546 farms raising various animal types have the potential for producing and utilizing their own biogas along with having electric powers ranging from 3 to 185 kWe. The biogas production has the capacity to inhibit GHG emissions which is equivalent to 55,745.1 tons of carbon dioxide solving both problems, the substitute for fossil fuels and appropriate management of animal manure.

2.5.2 Cost–Benefit Analysis of Biogas

2.5.2.1 Biogas Benefit

The cost–benefit analysis is the total value of biogas, a function of the net amount available, the conversion efficiency, and the value of fuel it replaces (House 2010). In addition to this, the fertilizer value of effluent is added as a benefit. The most usual practice for the disposal of MSW is landfilling. The treatment of organic solid wastes (accounting for about 70% of waste in the MSW) can divert a large part of the MSW from the landfill resulting in saving space and elongating the lifespan of the landfill. Besides, transport costs are also saved.

2.5.2.2 Environmental Benefits

The environmental aspect covers the advantages of an AD facility to the environment. The first and foremost being the reduction of the wood consumptions, which ends up in halt to the soil erosion conditions. The production of biogas plays a role in the global brawl counter to global warming. It acts as a substitute for natural gas and other fossil fuels polluting the environment. The use of the digestate reduces the consumption of artificial fertilizers, avoids carbon dioxide emissions, and deforestation is kept in check sustaining the capability of forests to act as carbon sinks (Kossmann et al. undated). All the benefits trail down to others as methane is reduced as a greenhouse gas by the contribution of anaerobic digestion.

2.6 Future Roadmap

Energy is an essential aspect for human and social development, but it is often produced at the expense of the environment and resulting in a plethora of environmental issues such as climate change (Khan et al. 2017). Biogas can help achieve sustainable development at both ends providing the ability to cope with an energy crisis and casting a positive impact on the environment with maximum utilization of waste. However, some research work is required to overcome different gaps (Theuerl et al. 2019).

International technical standards for the consumption of upgraded biogas should be established. The development of international standards, with the participation of public and private sector stakeholders, is an effective way to deal with the energy crisis and sustainability issues (Awe et al. 2017). Some states and countries like California, Germany, and Sweden are already following the national standards for the utilization of the biogas. The maximum use of biogas is also an alternative to natural gas (Yentekakis and Goula 2017). Bureau of India standards—designed and authorized in 2013–accounts for the use of biogas in the transport system and stationary engines (Jana and Bhattacharya 2017).

The utilization of biogas has different aspects ranging from smaller to a broader spectrum. It facilitates in the heat production, fuel for fuel cells, a source of energy for various industries, upgrading of the natural grids, and production of proteins and chemicals. In future Biogas plants require the solution for the indigestible residues that hamper the efficiency of biogas plants (Meyer-Aurich et al. 2012). More research should be carried out to practice more efficient pre-treatment methods, cost-effective and less energy-consuming technologies for reduced methane leakages, and other environmental effects. It is required to determine the maximum sectors for the utilization of biogas. The fuel cell provides good opportunity for the use of the biogas; however, innovations in the market benefits and technological development are required to maximize the effectiveness of fuel cells (Kapoor et al. 2019). In China, the potential of straw biogas requires its application on a large scale. A more appropriate study is required to maintain the quality and quantity of the biogas (Yu et al. 2019).

In China, biogas production is restricted to rural areas and engineered gaps that reduce the efficiency and cause practical problems. The marketization of renewable energy is needed to promote in China and several other countries (Adams et al. 2015).

European countries use a high amount of agricultural and animal manure to produce biogas. China alters agricultural waste to biogas energy that not only copes with the energy crisis but also an excellent way to tackle waste generation problem. Bioenergy production from biomass has put up 55 EJ of total global energy source in 2012. The palm oil industry of Malaysia is using more than 36 biogas projects in Cleaner Development Mechanism (Aziz et al. 2019). This can be considered in two aspects as it helps the company to sell the carbon credits and reduce GHGs emissions.

Germany has advanced technology for biogas production. Transfer and transport of technology to developing countries would encourage them towards more efficient and competent processes of energy production. Renewable Energies Act first came into being in 2000 and provides incentives on the feed used for renewable energy. There was a rapid increase in the number of biogas plants from 1050 to 8292 from the year 2010 to 2012. Approximately 50% of the biogas generation in European

Union is contributed by Germany (Gao et al. 2019). Biogas production in the United States of America is the ultimate source of renewable energy among solar and wind energy production. (Shen et al. 2015). Sweden is a country that uses biogas for vehicle fuel and power generation. Biogas consumption provides rapidly mounting markets; the number of biogas upgraded vehicles has increased more than 70,000 vehicles (Holm-Nielsen et al. 2009).

Pakistan's forest cover is less than 5% (Rahman and Paatero 2012). Pakistan has completed massive afforestation projects of billion trees in 2017 but almost 4000 MW energy deficiency and wood among the only source in hilly areas inclines people toward the use of natural resources. Such efforts of restoration could only be fruitful with the utilization of renewable energy (Kharl and Xie 2017). Energy and transport are the two sectors that use more oil compared to others. National resources of crude oil are not enough to solve the congestion so huge amount of oil is being imported to meet energy requirements. For example, 4.98 million metric tons of oil were imported during July, 2016 (Khan et al. 2019). For the developing countries, like Pakistan, biogas production can play a major role in fixing the bottleneck of the energy crisis and boost the economy. Biogas plant can save 92,062 PKR by treating 10 m^3 of organic matter that is an excellent addition in the economy and can be used to provide better facilities to the mounting population of Pakistan (Ali et al. 2019). Biogas, from poultry waste only, can facilitate the country with 300 MWh/day of electricity that not only accommodates energy shortage but also is environment-friendly (Ali et al. 2016). Biogas is a sustainable way that ensures the safety of biological and ecological sources. In Pakistan fuelwood is a common source of domestic energy requirements whereas deforestation has reduced the availability of the fuelwood. So, it provides an alternative to the consumption of forest that has shortened up to 8.8%. Biogas has a good potential to produce 2.5 kWh of electrical energy are produced only by 1 cubic meter of biogas. Biogas has a positive relation with human health (Gao et al. 2019).

According to Rahman and Paatero (2012) 98.6 million buffalos and 174 million cows in India can produce 601.46 and 1044 metric tons of manure per year, respectively (Raheem et al. 2016). This high amount of animal manure can be used to produce biogas, as a result of this, India is the top third emitter of CO_2 with 2 GT CO_2 per year can cut down its share from the global emission (Wang and Zhou 2020).

The electrical energy produced by the biogas obtained from agricultural waste is considered as zero emitters of CO_2 because emitted CO_2 was part of the plant body (Hijazi et al. 2019). Bioenergy is an irreplaceable and integral substitute to the unquenchable demand for energy in future and reduces the harvesting of fossil fuel (Kapoor et al. 2019), that is 82% globally with the annual emission of 35 Gt CO_2 and trend of emissions is increasing in non-Annex countries (Perera 2018).

2.7 Conclusion

Biogas production can address problems of energy demand, SWM system, fossil fuel consumption, and global warming at the same time. It is of more importance to developing countries, like Pakistan and India, where energy deficiency leads to excess utilization of non-renewable natural resources and where animal manure production is more than enough, 1645.46 metric tons per year, to support the sustainable way of energy generation. There is a wide range of biogas utilization such as heat production, electricity generation, and domestic fuel consumption. Biogas has proved to be a sustainable approach to many countries, e.g. in 2016, Germany has fulfilled its 12.4% of energy requirements from biogas plants. Sweden uses biogas for vehicle fuel and power generation. The carbon-based fraction of the waste is used to produce biogas. Biogas production utilizes the diversity of substrates and thus a diversity of microorganisms to act upon them. However, microbial and biotechnological advancements can increase the efficiency and yield of biogas production in various ways: by bio-augmentation and addition of microorganisms. There is diversity in the organic waste which can be utilized for biogas production by different countries according to the availability of feedstock types. Food waste generation rates are higher in developing countries. Various technology options can be opted for biogas production depending upon the financial and human resource capacity of the nations. Technological transfer to developing countries will be helpful in inefficient biogas production. States and countries like California, Sweden, and Germany have established standards for the consumption of biogas. It is imperative to develop International Standards for the utilization of biogas sustainably. More research is needed to develop cost-effective technologies, pre-treatment methods, and reduction of environmental effects. There exists a dire need for the marketization of renewable energy in several countries to promote its production and consumption.

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