Chapter

Recent Advances of Biogas Production and Future Perspective

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Abstract

The production of biogas via anaerobic digestion (AD) provides significant benefits over other techniques of bioenergy production. Biogas consists of several undesired components, such as H_2S, CO_2, nitrogen, hydrogen, oxygen, and water vapor, which contribute to lower the calorific value when compared with natural gas. The pollutants founded in low concentration effects the biogas commercial application in large scale, and therefore it must be taken out before usage. Various cleaning and upgrading techniques to improve the quality of raw biogas are discussed and categorized into physiochemical and biological technologies. Advanced techniques, such as hydrate separation, cryogenic separation, biological methods, membrane enrichment, in-situ upgrading, multistage and high-pressurized anaerobic digestion, represent the modern developments in biogas upgrading techniques. Biogas is a renewable green source of energy, and presently, it is utilized in a lot of developing countries as an alternative and energy renewable source for a broad range of applications. Most countries are in the process of instituting legislation to regulate the biogas industry. Biogas is considered to be the future of renewable and sustainable energy.

Keywords: biomass, biogas, biofuels, bioenergy, renewable energy

1. Introduction

The demand of energy has been increased over the years as the sequence by increasing of the world population [1]. Fossil fuels are exhausting and the emission products of these fuels have been causing some damages to the environment. The scientists in the world are focusing on developing alternative methods of energy production [2]. Bioenergy is an energy obtained from any fuel that is originated from biomass, which includes recently living organisms and their metabolic by-products [3]. Biomass is defined as all animal and plant material on the Earth's surface. Hence, collecting biomass, such as manure, crops, or trees, and employing it to produce electric power, heat, or motion is bioenergy [4, 5]. If not managed optimally, the large amounts of biomass, livestock's manure, agro-industrial waste, and slurries produced today as well as the wet organic waste streams represent a constant pollution risk with a potential negative impact on the environment [6]. Biofuels are defined as fuels made from biomass resources, or their processing and conversion derivatives [3, 5]. Biofuels are eco-friendly and renewable resources of energy and hence have been receiving attention as an alternative energy source [2]. The organic part of nearly any form of biomass, involving industrial effluents, sewage sludge, and animal waste, can be decomposed via AD into carbon dioxide and methane mixture called as biogas and is considered an alternative green energy resource. Methane (CH_4) is the most important component of biogas because it has the highest energy density among the biogas components. Therefore, the high CH_4 content of biogas is desired [7, 8]. Biogas was first identified 600 years ago as originating from decomposing organic matter. More recently, in 1884, Louis Pasteur investigated it sourced from animal waste, suggesting it as an appropriate fuel for the lighting of street lamps. Biogas primarily consists of methane (CH_4), in a range of 50–75%, and carbon dioxide (CO_2), at 25–50%, with minor amounts of other compounds, such as hydrogen (0–1%), nitrogen (0–10%), which could originate from air saturated in the influent, vapor water (H_2O) at concentrations of 5–10%, or higher at thermophilic temperatures, derived from medium evaporation, hydrogen sulfide (0–3%), which is produced from reduction of sulfate contained in some waste-streams, ammonia (NH_3) originating from hydrolysis of proteinaceous materials or urine and oxygen (0–2%), which is entering the process from the influent substrate or leakages, hydrocarbons at concentrations of 0–200 mg/m^{-3}, trace carbon monoxide (CO), and siloxanes at concentrations of 0–41 mg m^{-3}, originating for example from effluents from cosmetic medical industries. The relative content of CH_4 and CO_2 in biogas is mainly dependent on the nature of the substrate and pH of the reactor [7–19]. Typical components and impurities influence the quantity and quality of the biogas. CO_2 and N_2 lowers the calorific value, CO_2 also causes corrosion and damages to alkali fuel cells. H_2S spoils catalysts, causes excessive corrosion and deterioration of lubrication oil, generates harmful environmental emissions, and corrodes the engines of biogas purification machinery. N_2 and NH_3 increase the anti-knock properties of engines and NH_3 also damages fuel cells. Water vapor causes corrosion of equipment and piping system leading to damage instruments and plants. Siloxanes acts like an abrasive and damages engines. Dust blocks nozzle and fuel cell [18–23].

Biogas is flammable, smokeless, hygienic, colorless, odorless, and has bad eggs odor whether not desulfurized. It has an energy content of 37.3 MJ/m^3, explosion limits 6–12% biogas in air, ignition temperature 650–750°C, specific gravity 0.847–1.004, and calorific value 4740–7500 kcal/Nm^3 [18, 24–28]. Biogas is an environmentally friendly, a renewable, clean, cheap, high quality, and versatile fuel which is generated in digesters filled with the feedstock. It is considered an alternative green energy resource. It can be utilized for different energy services like heat, combined heat and power, or a car fuel [7, 8, 29].

Biogas technology is used to convert the organic waste into energy. The use of energy and manure can lead to social economic benefits, green environment, and also contributes towards sustainable development [30–32]. Biogas technology is also a source of nutrient-rich organic fertilizer and the effluent slurry produced as a result of biogas technology is also helpful for algae growth, fish production, and seed germination [24]. Biogas technique is applied to small-scale and large-scale uses involving electric power production. It is a mixture of gases of which the composition relies on substrates and AD process conditions like retention time, temperature, and pH. Biogas is one of the main products of the AD of organic substances.

Anaerobic digestion (AD) is considered as a biological process that degrades organic substances by the actions of microbial communities in the absence of oxygen. In fact, AD can be divided into four stages, as seen in **Figure 1**, which are hydrolysis, acidogenesis and this stage is considered as acid-producing, acetogenesis

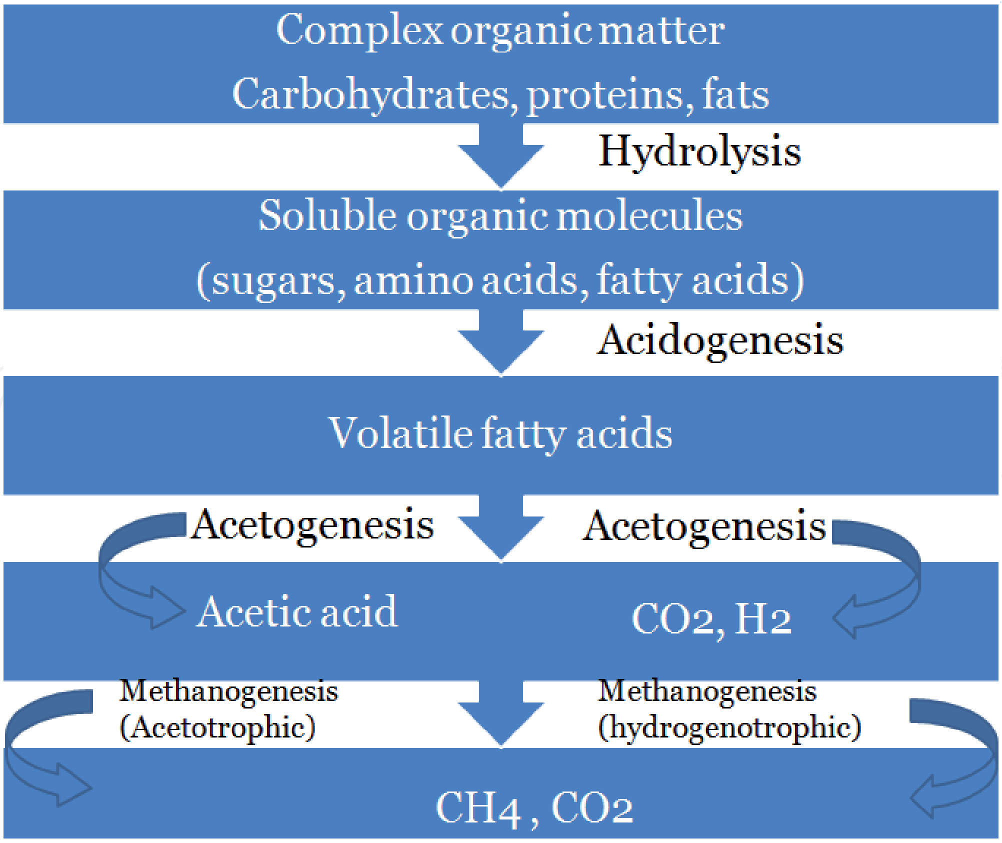

Figure 1.
The steps involved in anaerobic digestion.

and this phase is also called acetic acid-producing, and methanogenesis and this final step is known as methane-producing [8]. It is quite important to purify raw biogas and upgrade it to a high-quality fuel standard, in order to increase the calorific value and reduce undesired components, such as H_2S and CO_2, which are damaging the utilization systems. This process is well known as biogas cleaning and upgrading [33, 34]. Biogas could be simply upgraded into biomethane or renewable natural gas (RNG), which is similar to natural gas that produced from nonrenewable fuel sources. It contains about 90% or greater of methane. RNG could be replaced for natural gas and could be used as fuel for cars that can run on natural gas and to provide gas to natural gas grid. Upgrading of biogas to biomethane is considered as one of the technologies that has got a lot of attention in the bioenergy industry [8, 35]. Biogas could play a key role in the developing market for renewable energy and the utilization of biogas in the world is expected to be doubled in the next years, ranging from 14.5 GW in 2012 to 29.5 GW in 2022 [20, 36, 37].

2. Renewable energy resources

The term energy can be generally defined as the amount of force or power when applied can move one object from one position to another, or it defines the capacity of a system to do the work. The most important characteristic of energy is the possibility to convert one of its forms to another. Generally, the energy technologies are the man-made devices, equipment, and systems used to capture, convert, store, and transport energy from the energy resources [38]. Energy is an important demand in our daily life as a way of enhancing human development leading to productivity and economic growth. Energy is a key driver for agriculture, industries, and service sectors that influence economic development [39]. The term energy sources refer to the output forms of energy from the man-made energy technologies, while the energy resources refer to the naturally available forms of energy [38]. The resources of energy are divided into three groups: nuclear resources, renewable resources, and fossil fuels [40]. Renewable energy is called "renewable" because the sources harnessed to create the energy renew and replenish themselves constantly and within a reasonably short period of time (i.e., months or years, not centuries) [41]. Thus, renewable energy sources renew themselves naturally without being drained in the earth [39, 41]. Renewable energy techniques give a great opportunity for reduction of greenhouse gas emission and decreasing global warming via replacing traditional energy sources [6]. Various types of renewable resources such as hydrothermal, geothermal, solar, wind, ocean (tide and wave), heat from the Earth's interior, and biogenic (biomass) energies are available and they give the possibility to produce consistent power [38]. These renewable energy sources are also often called alternative sources of energy [42]. Alternative or renewable energy sources include traditional renewable energy technologies (such as wind turbines) as well as innovative new technologies, such as hydrogen internal combustion engines, and hydrogen-based fuel cells [38].

There is a direct relationship between renewable energy and sustainable development via its effect on human development and sustainable economic growth [43]. Renewable energy sources supply a lot of opportunities in reduction of environmental and health impacts, energy access, energy security, climate change mitigation, social, and economic development [6, 38, 44–46]. Renewable energy resources will play an important role in the world's future [6, 40]. The technologies developed to exploit renewable energies are known as renewable energy technologies (RET) or clean technologies or green energy. Sustainable economic and industrial growth also requires safe and sustainable energy resources [47–49]. Maximizing resource (material and energy) recovery and minimizing environmental impacts such as contribution to the global warming are important objectives in the solid waste management (SWM) sector, which is considerably developed over the past century [50, 51].

3. Sources of biogas

There are a variety of wastes that can be used as sources, or feedstocks, that are fed into the digester to produce biogas. Most of biodegradable organic compounds could be transformed into biogas by anaerobic digestion, and biodegradability is the characteristic indicating to what extent this is possible. Raw materials for producing biogas by anaerobic digestion are biomass feedstocks which include; municipal solid waste (MSW), industrial solid wastes and industrial wastewaters, food waste, livestock manure, sewage sludge, agricultural manures, catch crops, energy crops, and microalgae [12, 52–57]. The largest resource is represented by animal manure and slurries from cattle and pig production units as well as from poultry, fish, fur, etc. [58–61]. Manure of animal is considered as a main carbon source for biogas and involves pig manure, cattle, and poultry. The total solids present in animal manures consist of 90% moisture content and volatile solids. It performs as perfect substrate because of its great buffering capacity [62–64]. In most countries, sewage sludge and agricultural manures have been the principal sources for some time, complemented by slaughterhouse, dairy, and restaurant waste. More recently, biogas plants are increasingly using municipal solid waste (MSW), industrial solid wastes, and industrial wastewaters as feedstocks [12].

Nowadays, sludge from municipal wastewater treatment plants is considered as major source of organic matter for biogas generation in Sweden. Other familiar substrates for biogas generation in co-digestion plants involve source-sorted food waste and manure, slaughterhouse waste, and waste from the feed and food industries [65]. Sewage sludge is usually used as a feedstock to provide energy to power sewage treatment works. For many years, sewage sludge and agricultural manures was the principal inputs, making up over 80% of the total.

However, more lately, the manufacturers have been testing with biogas particular agricultural crops, involving maize and rapeseed. Both the crop itself and the generated fodder (silage) are utilized. Animal waste is increasingly used as a feedstock throughout the world. In the EU, there are now over 750 biogas plants processing animal waste, many of them on a large scale. Organic waste from households and municipal authorities is also an important source of biogas [12].

The urban solid waste production, or municipal waste, increases with population growth, high economic activity, and goods production. Biogas has the potential to be produced from widely available, abundant raw materials, including agricultural residues (e.g., animal manure), landfill and food waste, and aquatic biomass and lignocellulosic raw materials [66, 67]. Wood, agricultural residues, and dung of animal are the sources of energy for biogas technique [24, 68]. The use of wastewater from inorganic sources, such as chromium, has also been studied as an alternative for energy production, a more environmentally sustainable approach that avoids landfill disposal of these wastes [69, 70]. Industrial waste and wastewater have potential uses in biogas production due to their characteristics, such as high organic load [66, 71]. Algae are considered as a potential biomass feedstock for decreasing our dependence on nonrenewable energy sources for electric power, transportation, and heat production [53].

Livestock manure, i.e., dung of cow is an efficient feedstock for biogas production getting high cumulative biogas yield with steady performance, with a continuous process. Therefore, cow dung is more favorable in the biogas process [72, 73]. In general, there are different kinds of biomass resources to produce biogas, including animal manures, municipal solid wastes, food wastes, industrial wastes, agricultural residues, poultry wastes, forestry wastes, microalgae, and some dedicated energy crops [54–57].

4. Biogas production processes

Generation of biogas gives a multiuse carrier of renewable energy, as methane can be utilized for substituting of nonrenewable source of fuels in both heat and electricity production and as a car fuel. AD of wastes, energy crops, and residues is of growing interest in order to decrease the greenhouse gas emissions and to promote a sustainable development of energy supply [74]. Anaerobic digestion is a technology with proven efficiency, being widely used in the stabilization of industrial wastewater, urban solid waste, animal manure, and sewage sludge [66]. There are many benefits associated with anaerobic digestion technology, which include mass reduction, odor removal, pathogen reduction, less energy use, and more significantly, the energy recovery in the form of methane [75, 76]. The aim of anaerobic digestion process is the production of a methane-rich biogas through biological decomposition of organic matter, in an oxygen-free environment. An aerobic digestion is considered as a low-cost an eco-friendly waste management process, thus it reduces the emission of greenhouse gases. In the meantime, it stabilizes and reduces the wastes. One of the major advantages of an aerobic digestion is its adaptability to deal with a wide range of organic substrates. The produced biogas can be used for power and heat production, or can be upgraded and used as vehicle fuel in the transport sector. In addition, the by-product of AD, the "digestate residue," can be further utilized as a fertilizer on the agricultural land [50]. There are different process types which can be applied for biogas generation, which are classified in dry and wet fermentation systems [21, 77, 78]. Wet digester systems are constantly applied using vertical stirred-tank digester with various stirrer kinds dependent on the source of the feedstock.

Biomass is utilized as substrates for biogas generation as long as it consists of hemicelluloses, cellulose, carbohydrates, proteins, and fats as major constituents. Only powerful lignified organic materials, e.g., wood, are not suitable due to the slowly anaerobic decomposition. The composition of biogas and the methane yield depends on the feedstock type, the digestion system, and the retention time [78]. Maximal gas yields and theoretical methane contents of substrates for biogas production are carbohydrates 790–800 biogas (Nm^3/t TS), 50% CH_4 and 50% CO_2, carbohydrates only in the form polymers from hexoses, not inulins and single hexoses, raw protein 700 biogas (Nm^3/t TS), (70–71)% CH_4 and (29–30)% CO_2, and finally raw fat 1200–1250 biogas (Nm^3/t TS), (67–68)% CH_4 and (32–33)% CO_2 [79].

4.1 Biochemical process

Anaerobic digestion involves bacterial fermentation of organic wastes in the absence of free oxygen. Methane fermentation is a complex process, the fermentation leads to the breakdown of complex biodegradable organics in a four-stage process: hydrolysis, acidogenesis, acetogenesis, and methanogenesis [50, 74, 80].

First stage (hydrolysis process): large protein macromolecules, fats, and carbohydrate polymers (such as cellulose and starch) are broken down through hydrolysis to amino acids, long-chain fatty acids, and sugars.

Second stage (acidogenesis process): the products obtained in first step are then fermented via acidogenesis to form volatile fatty acids, valeric acid, propionic, principally lactic, and butyric. Third stage (acetogenesis): bacteria devour these fermentation products and produce acetic acid, hydrogen, and carbon dioxide. Fourth stage (methanogenic): organisms feed on the hydrogen, acetate, and a few of the carbon dioxide to generate methane [81]. Three biochemical pathways are used by methanogens to achieve this:

$$4CH_3COOH \rightarrow 4CO_2 + 4CH_4 \ (\text{acetotrophic pathway}) \tag{1}$$

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O \ (\text{hydrogenotrophic pathway}) \tag{2}$$

$$4CH_3OH + 6H_2 \rightarrow 3CH_4 + 2H_2O \ (\text{methylotrophic pathway}) \tag{3}$$

Biogas is a multipurpose renewable green energy source, which can be simply used to substitute nonrenewable energy source, in heat and power generation, and as gaseous car fuel. Biomethane can also substitute natural gas as a feedstock for producing chemical materials. The biogas generation during AD provides vital benefits over other bioenergy generation technologies. It is admitted as one of the most energy-efficient and environmentally beneficial technology for generation of bioenergy [82, 83]. Anaerobic digestion is a broadly used technology that provides some benefits over other biofuels generation ways, such as, sustainable biogas production, option for using wastewater and sea water, lower operational costs, maximum biomass utilization, minimum sludge production, lesser energy consumption, and feasibility to recycle nutrients [54, 84, 85].

AD of animal manure provides some socio-economic, environmental, and agricultural benefits via inactivation of pathogens, improved fertilizer quality of manure, and considerable reduction of odors, and last but not least production of biogas generation, as green renewable fuel, for multiple utilizations [58]. The slurry or digestate from the reactor is affluent in ammonium and other nutrients utilized as an organic fertilizer [86, 87]. The European renewable energy directive has set a target to substitute 27–30% of the total energy consumption with renewable energy sources by 2030. It is expected that 14–26% of this renewable energy target could be achieved by biogas from farming and forestry residues [61, 88]. Biogas is presently produced and utilized in Europe. In 2007, Germany was the largest biogas producer in Europe mainly from energy crops, while the UK was the second producer of biogas mainly from landfill sources [50].

There are three common technologies used (in **Figure 2**) to convert biomass to green sustainable products. Thermal approaches that are commonly used to convert biomass into an alternative fuel are: gasification, liquefaction, pyrolysis, and charcoal, while there are two biological approaches that are commonly used to convert biomass into bioenergy: fermentation and anaerobic digestion, as shown in **Figure 2**. This research is going to focus on an anaerobic digestion to produce biogas.

The anaerobic co-digestion is a choice to settle the drawbacks of single substrate digestion system, being the properties of the substrates and chemical composition, the operating parameters (pH, charge rate, temperature, etc.), the bioavailability, biodegradability, and bioaccessibility, significant parameters to be optimized.

Some of raw materials need to be treated to improve the biogas production. In the past, AD was mostly referred to a single substrate/single output process but recently, co-digestion has become a standard technology in agricultural biogas production in many countries [50, 66]. The anaerobic co-digestion is the simultaneous digestion of more than one substrate with complementary characteristics and has become popular as the digestion of several materials can give higher methane yields than those expected when single materials are treated individually [91–93]. Several of the reasons related with the improvement are associated to the combinations of substrates that result in a positive interaction within the system, reducing negative influences of toxic or inhibitory compounds, affecting C/N ratio and reactor stability, supplementing nutrients, and balancing buffer capacity. Additional benefits of using co-digestion techniques including improved balance nutrients, synergistic effect of microorganism, increased load of biodegradable organic matter, and higher biogas yield [50, 82, 94, 95].

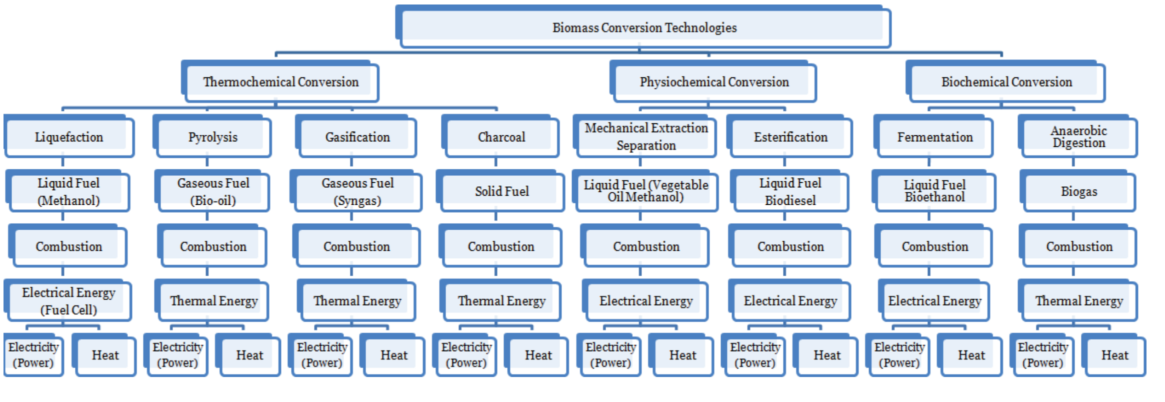

Figure 2.
A schematic of various biomass conversion technologies [5, 89, 90].

4.2 Factors affect biogas production

Production of biogas involves a series of four complex biochemical processes (hydrolysis, acidogenesis, acetogenesis, and methanogenesis) depending upon different factors such as type of substrates, substrate particle size, temperature range, pH, carbon/nitrogen (C/N) ratio, and inoculums concentration [62, 96–99]. There are various factors affecting biogas production from anaerobic digestion. Some of the key factors have been elaborated in detail below.

4.2.1 Hydrogen-ion (pH) concentration control

The hydrogen-ion (pH) concentration in the digesting material affects the anaerobic digestion process. The hydrogen-ion concentration of the culture medium has an immediate effect on microbial growth due to the digestion is prevented by surplus acidity [100, 101]. Methanogens grow better under neutral and a bit alkaline environments. They are died by acidic conditions. Upon stabilization of the aerobic digestion process, the optimum values of pH in the system will be in the range of 7–8.5 with values near to 7 for optimal activity [21, 96, 102–105].

4.2.2 Temperature control

The temperature of MSW influences the success of the digestion process, as the activities of the anaerobes causing waste decomposition are temperature dependent. Optimum performance of an aerobic digestion system is affected largely by the operating temperatures of the reactor. There are three general ranges of temperature each favoring a specific type of microorganisms including; psychrophilic: about 10–20°C, or less than (<30°C), mesophilic: about (30–40°C), and thermophilic: about (50–55°C), or may reach 60°C [50, 106]. Previous studies have shown that anaerobic bacteria exhibit the highest activity within the mesophilic and thermophilic ranges [107]. Extreme cases of either very high or very low temperatures kill the anaerobes, hence inhibiting the whole AD process [96]. The rate of decomposition and gas production is sensitive to temperature, and, in general, the process becomes more rapid at high temperatures [3, 102]. The optimum temperature is 35°C [101, 108]. There are a couple of factors, which contribute to heat generation or transfer in a digester including process reaction, mixing (impellers), as well as heat exchangers (hot water or steam) [50].

4.2.3 Feedstock composition and nutrients

A variety of digester kinds exists for the anaerobic treatment of organic wastes.

Some diversity of biomass feedstocks could be used by anaerobic digestion techniques such as biowaste, agricultural crops, human waste, municipal sewerage and animal manure among others. The quality and quantity of the biogas yield is determined via nature of the feedstock used. Furthermore to the biogas yield, biomass generates vital nutrients and carbon that promote the sustainable growth of the microbes [96, 107, 109]. The selected kind rely on operational factors, involving the nature of the waste to be treated, e.g., its solid content. The Oregon Department of Energy [110], in its classification of kinds of digester, elucidates that "a plug-flow digesters are appropriate for ruminant animal dung having solid concentrations of 11–13%"; "a complete-mix digester is appropriate for manure that is 2–10% solids"; and "a covered lagoon digester" is used for liquid manure of less than 2% solids. The amount and kind of solid contents of the waste they considered were such that the wastes are able to flow on their own or forming slurries with water and finally flowing, and thus can be used in a continuous operation [102].

4.2.4 Carbon/nitrogen (C/N) ratio

The concentrations of carbon and nitrogen determine the anaerobic digestion performance. Anaerobic digestion ideally occurs at C/N ratio ranges between 20:1 and 30:1. For the optimal operation, the ratio of the carbon, to, nitrogen should be about 30:1 in the raw material. Methanogenic bacteria use nitrogen to meet their protein requirements. Whereas, carbon constitutes the energy source for the microorganisms, nitrogen serves to enhance microbial growth. If the amount of nitrogen is limiting, microbial populations will remain small and it will take longer to decompose the available carbon [102]. Consequently, in cases of high C/N ratios higher than the optimum ranges, the nitrogen will be promptly consumed by the bacteria and thus will not react on the excess carbon in the feedstock, hence decreasing the biogas yield. For cases of lower ratios than the limited range, the excess nitrogen will result into ammonia (a strong base) formation, thereby increasing the working pH over the required 8.5 inhibiting the microbes and finally dropping gas generation rates [96, 107]. It has been found that the bacteria in the digestion process use up the carbon present 30–35 times faster than the rate at which they convert nitrogen [102]. The high amount of nitrogen content in animal manures reduces its utilization in anaerobic digestion for biogas generation because of its C/N ratio [62, 111]. To solve this problem, nitrogen-free raw material or carbohydrate-rich source is used to raise the carbon content in the animal manure before the AD process proceedings [62].

4.2.5 Substrate particle size

Pretreatment of biomass should be processed to reduce the particle size and then followed co-digestion to increase the biogas production [62, 112]. The substrate for anaerobic digestion has to be composed of digestible particle sizes. Smaller particles raise surface area for the microbial action of the methanogens as a result growing the biodegradability of the feedstock, hence raising the rate of biogas generation and vice versa for great particles which may clog the digester [96, 113, 114].

4.3 Pretreatment technologies used in biogas production

A number of various treatment processes presently exist for the organic waste management; some more technologically modernized than the others, and some more founded in some countries where the legislation and policy promotes for certain environmental goals. The four alternative systems are currently applied worldwide, i.e., Landfilling, Aerobic Composting, Incineration and Anaerobic Digestion (AD). Anaerobic digestion of organic waste is the most desirable management method and this research is going to discuss it in detail [50, 115, 116].

Organic waste is considered extremely heterogeneous, whereas its moisture content as well as level of impurities differs significantly. Hence, pretreatment before an aerobic digestion is a main process. Diverse types of pretreatment technologies have developed and are successfully installed in many anaerobic digestion plants in the worldwide. The organic waste pretreatment is considered as the major process step in biogas generation plants ensuring flexibility to treat different types of organic waste, efficient extraction of contaminants, high availability of AD plants, substrate homogenization, wear resistance, high biogas yields, energy efficiency, and production of high-quality fertilizers. Organic waste almost includes contaminations, such as glass, metals, stones, and sand; additional systems are also required to deal with such heavy contaminants of the waste. Thus, pretreatment techniques, may be mechanical (e.g., milling), chemical (e.g., acid or alkali treatment), or thermal methods (e.g., steam explosion), are usually applied. Novel pretreatment methods are emerging, which focus on ionic liquid or supercritical CO_2 to solubilize and collect lignin, both increasing biogas production, while also providing additional revenue through lignin collection. Regardless of the pretreatment technique used, this step is an essential consideration for improved biogas production from lignocellulosic feedstocks [50]. In any AD application treating organic waste, a mechanical pretreatment is installed.

A critical unit in industrial biogas plants is mechanical pretreatment; it possibly contains pulpers and shredders. These apparatus are utilized to improve the surface area of tough solid substrates [such as municipal solid wastes (MSW), cardboard, mixed industrial wastes, bulky refuse, waste tires, waste wood and waste papers, etc.] via crushing and breaking down, leading to their more efficient digestion and improved AD process. Different pretreatment technologies are available to reduce the size of the organic waste and to separate the plastic and packaging material from the biodegradable fraction of the waste. Thereby, plants are generally highly flexible to treat all kinds of organic waste without any quality restrictions. Sewage sludge or agricultural biomass, e.g., straw are difficult to degrade an aerobically due to their rigid structure. Therefore, organic waste thermal treatment at high pressure and temperature values is more familiar when treating such types of organic biomass. In contrast, food waste can be efficiently converted in anaerobic digestion systems to biogas by mechanical processing. An efficient pretreatment of organic waste also ensures the production of high-quality fertilizers and hence, the recycling of valuable nutrients back into the natural cycle is achieved and additional, expensive digestate processing after AD can be avoided. High biogas yields in anaerobic digesters are achieved, whether the biodegradable organic material is well crushed in the pretreatment and a large surface are for microbial degradation is achieved [50].

The composition of organic waste come from different areas (commercial, municipal, industrial) differs significantly. The most critical criteria for the selection of an appropriate pretreatment technology are waste composition. Moreover, for the selection of the most appropriate pretreatment system, it is significant to know which kind of AD, i.e., dry or wet digestion systems, should be used to treat the organic waste. Wet anaerobic systems use pretreatment technology to take out the undesirable pollutants before the anaerobic digestion process and are operated at a lower solid concentration. The digestate after anaerobic digestion may be used immediately as high-quality fertilizer and no further digestate treatment (compost refining, post-composting, etc.) is usually required. Amount of biogas generation is high due to the efficient organic waste pretreatment. The preferred technologies to treat wet organic waste such as food leftovers, food waste, packaged food, and organic fraction of MSW are Wet anaerobic digestion systems. Dry anaerobic systems use simpler pretreatment technology before the anaerobic digestion process and are operated at higher solid concentrations. As the efficiency of impurity separation is not enough to utilize the digestate immediately as high-quality fertilizer, further digestate treatment (i.e., compost refining, post-composting) is normally necessary to know whether the input substances are polluted.

Dry anaerobic technology are mostly utilized to know whether the organic waste involves a high percentage of garden waste and also after a mechanical extraction process can be used to treat the organic fraction of MSW [50]. Dry anaerobic digesters are higher solids loading and biomass retention, controlled feeding and spatial niches, pretreatment is simpler, but it has complex and expensive transport and handling of waste, material handling and mixing is difficult, and only structured material can be used [117]. For processing dilute organic slurry with a total solid content of maximum 10–15%, the wet systems are designed. Substrates consist of total solid higher than 15% will be co-digested with co-substrates of lower total solid content, or usually diluted with recirculated or fresh process water. Various ranges of low solid substances have been successfully treated by wet AD technology, involving food industrial effluents and sewage sludge. In contrast, in solid-state fermentation processes, also called dry digestion, the substrates used have high solid content (25–40% TS), thus an essentially different technical approach regarding the waste handling and treatment is needed [50, 118]. Due to the high viscosity in the dry digestion systems, heat and nutrient transfer is not as efficient as it is in wet processes, therefore mixing is very important to prevent local overloading and acidification [119]. In spite of that, conventional mechanical mixers are not appropriate for solid-state processes; instead, recirculation of the waste or re-injection of the produced biogas is often used in these types of reactors to solve the mixing problems [50, 120]. The main benefits of wet anaerobic digesters is dilution of inhibitors with fresh water, but it has some drawbacks including scum formation during crop digestion, high consumption of water and energy, short-circuiting, and sensitive to shock loads [117].

5. Operational methods and reactor designs

Digesters established in worldwide differ in their costs, construction materials, and design complexity [121, 122]. In order to design any anaerobic digester, we need to solve three principal requirements such as: to produce a high volume of high-quality biogas; able to continuously handle a high organic loading rate; and to have a short hydraulic retention time in order to have smaller reactor volume. There are various types of digesters, which are mostly used in the industry involving multistage systems, batch, continuous one-stage system, or continuous two-stage. Further configurations, such as the plug-flow systems, anaerobic sequencing batch reactor (ASBR), tubular reactor, baffled digesters (ABR), upflow anaerobic sludge blanket (UASB) reactor, and anaerobic filters, are also present [50, 104, 123]. Normally, the selection of suitable digester kind is relying on the properties of the main feedstock used, specifically total solid. Feedstocks with high amount of total solid and slurry are generally treated in CSTRs; whereas, soluble organic wastes are mainly digested in upflow anaerobic sludge blanket (UASB) reactors, anaerobic filters, and fluidized bed reactors [124]. Co-digestion is principally implemented in wet single step processes (e.g., CSTR). Continuous systems are fed continuously, while the digestate residue is discharged at the same rate, allowing a steady state to occur, leading to a constant gas production rate. In spite of that, this kind of operation is only possible for substrates, which can be pumped for continuous feeding. Otherwise, a semi-continuous process is applied with a discrete amount of feed several times a day [50]. The main advantages of continuous systems are simplicity in design, operation, and have low capital costs, but they have disadvantages including rapid acidification and larger volatile fatty acids (VFA) production [117].

5.1 Continuous flow stirred-tank reactors (CSTRs)

Continuous flow stirred-tank reactors (CSTRs) are one of high rate digesters and probably the most generally used reactor configurations in biogas generation. They are interesting because of the simplicity of their design compared to other types of biogas digesters. Normally, CSTRs are usually utilized to process slurries with total solids content of 5–10% [50, 125]. Slurries of animal manure and organic industrial wastes are treated using CSTRs. As a disadvantage, CSTRs have long retention times [126] and may be more energy intensive than some of the other types of reactors. Performance of CSTRs is improved by recycling microbial solids, or enhancing retention of the active biomass [50].

5.2 Anaerobic plug-flow reactors (APFRs)

Anaerobic plug-flow reactors (APFRs) are generally long rectangular channels, with the flow entering one end and leaving at the distant end. There is roughly seldom mixing in the flow direction. The channels, or tanks, are mostly placed above ground. Both thermophilic and mesophilic operations are utilized [50, 127]. APFRs are considered one of high rate digester and commercially used for treating different types of organic wastes involving slurries of animal manure, distillery wastewater, and the organic fraction of municipal solid waste [128, 129]. Compared to a single-stage CSTR, plug-flow reactors are mostly more efficient in converting the substrate to biogas and are more stable to operate [50, 130].

The two generally utilized reactor kinds are: continuous stirred-tank reactors (CSTR, using biogas recirculation for mixing or mechanical agitation or effluent), and plug-flow reactors (PFR, where the reactor content is shoved along a horizontal reactor). In dry digestion processes, PFRs are usually utilized to treat substrates with high solid content [131], whereas CSTRs are applied in wet digestion systems. The choice of wet or dry digestion technology relies on the total solid content (TS) of the material treated [50]. Recovery of biogas from manure is widely applied with CSTR and PFR systems in developed countries, likewise covered lagoons, and other kinds of anaerobic reactors are also used [74].

5.3 Anaerobic contact reactor (ACR)

Anaerobic contact reactor (ACR) is consistently a fully mixed mechanically stirred tank with recycle of sludge. The effluent from the tank flows into some kind of a solid-liquid separator (e.g., gravity sedimentation tank, sludge flotation device, lamella clarifier) and the recovered solids are returned to the anaerobic digester. ACRs are efficient of treating high-strength waste with a high concentration of digestible solids due to high concentration of active microbial biomass [132–134]. Hydraulic retention times are short and fluctuations in organic loading are well tolerated. The ACRs are relatively less affected to souring and other inhibitors [128, 135, 136]. Stirred digesters coupled to some type of membrane-based cell retention have proved highly effective in biogas production [50, 137, 138].

5.4 Biofilms

Biofilms are microbial consortia attached to a support material. The support surface is usually inert and may be fixed or suspended. Anaerobic microbial biofilms can effectively digest organic material to produce biogas [139]. A huge mass of immobilized biofilm and mass-transfer upgrading motion of liquid around the film let biofilm reactors to hold high organics loading and bear well any fluctuations in hydraulic or organics loads. Once the biofilm has produced, start-up periods are short compared to the other traditional anaerobic treatment systems [139, 140]. The support material nature affects the improvement of the biofilm and its intensity of attachment, or mechanical steadiness [50, 141].

5.5 Batch reactors

Batch reactors are quick, require inexpensive equipment, and are the simplest to operate since they are fed with feedstock and left for a longer period before being emptied. No mixing, stirring, and pumping required, low input in terms of process and mechanical demands, and low capital cost, but they are channeling and clogging and these types of reactors have larger volume and lower biogas yield. The methane production is commonly the highest at the beginning and decreases toward the end of the process as the substrate is being utilized [117, 140, 142].

5.6 Anaerobic baffled reactor (ABR)

Anaerobic baffled reactor (ABR) is a modification of Upper-flow Anaerobic Sludge-Bed Reactor. Anaerobic baffled reactor (ABR) initially gets the organic fraction of municipal solid waste (OFMSW) accompanied by decomposition process of the materials and eventually generates biogas by microorganisms' activities. This kind of reactor can possibly treat wastes with high solid content, and thus, it may be a viable alternative in some situations observed in developing countries. The raising contact time with the sludge (active biomass) results in treatment improvement. ABRs are powerful and able to treat a broad range of wastewater, but both remaining effluents and sludge still require additional treatment in order to be discharged or reused correctly [121, 143].

5.7 Hybrid bioreactor

Hybrid bioreactor represents the modern production of reactor with possibility to incorporate the benefits of both suspended solid and biofilm reactors. These types of reactors provide the benefits of the UASB concept related to the ones of the anaerobic filters, and nowadays can be considered more appropriate for the treatment of a sequence of soluble or partially soluble wastewater than other reactor systems. Hybrid reactor (combination of the basic types) and anaerobic baffled reactor (ABR) fall under this category [143–145].

Anaerobic digestion may consist of a single-stage operation, or a two-stage process. Single-stage operation is less efficient, but most commonly used because of its simplicity. Traditional single-stage digester is generally larger, and hence takes more energy to mix and heat compared to a two-stage digester; while, a two-stage digestion is more efficient overall compared to a single-stage process [50, 146–150]. Many different configurations and operational systems have been developed for anaerobic digesters for use in different applications. The goals normally are to shorten the start-up period, reduce operational instabilities, decrease washout of active biomass, and attempt to better accommodate the inevitable variations in feed composition. Operation, maintenance, and installation cost are other factors that substantially impact the economics of biogas generation.

Single-stage digesters are most typically utilized on account of their simplicity, but overall two-stage digesters are more effective. There is no specific digester kind can be recommended as being internationally appropriate. The selection in a given scenario has to consider a lot of factors involving the following: the prospects for disposal of the digestate and the effluent; nature and strength of the waste stream; the availability and skills level of the local workforce; local climatic conditions, infrastructural support and cost of energy; and the expense of construction and operation. Generation of biogas by AD is a helpful method to recover energy from organic waste, whereas considerably reducing the environmental effect of the waste [50]. In addition, the CSTR design is normally performed in single-stage systems, there the reactor operates, favoring both methanogenic and acidogenic microorganisms. These types of systems have lower capital and operating costs and are simple to operate, making them attractive for a broad range of applications through the last decades [151, 152]. Furthermore, the conversion of organic material to biogas is implemented during a series of biochemical reactions, which do not inevitably have the identical optimal environmental conditions. Single-stage digesters have simple design with less technical failure. In the other hand, it has higher retention time, and form foam and scum leading to potential failure [50, 117, 153]. In order to get higher reaction rates and hence a higher biogas yield, two- and multistage systems have developed to give optimal conditions for the various groups of microorganisms included in the degradation process [50, 153]. Four processes (hydrolysis, acidification, acetogenesis, and methanogenesis) in AD are separated in two-stage reactors. Thus, the first stage can be operated at lower pH, which is more favored for the growth of acidogenic and hydrolytic microorganisms; whereas, the second phase is operated to prefer the growth of methane forming microorganisms [154]. In the second step, the rate of limiting factor is normally the rate of microbial growth [155] since longer generation times for methane-producing archaea, and thus longer biomass retention times are required in this second stage, which in turn improves the biogas yield [118]. These kinds of digesters usually have a more steady performance than single-stage digesters, since they do not bear from the process disturbances caused by ammonia accumulation and the changes in the pH [155, 156]. Best phase extraction option can be given in multistage reactors, which can provide optimization and process control for each conversion point, leading to raised methane generation [50, 157]. Two-stage reactors increase in biomass digestion due to recirculation, it has constant feeding rate to methanogenic stage, and it is more robust and less susceptible to failure. In contrast, it has complex design and expensive to build and maintain, and solid particles need to be removed from the feedstock in the second stage [117].

6. Biogas technologies

There are undesired compounds and other gases contained in biogas are unwanted and are considered as biogas pollutants [11]. The concentrations of these impurities are dependent on the composition of the substrate from which the gas was produced [158]. The removal of these harmful components and other non-combustible gases makes biogas a more viable and economical alternative renewable energy source [96, 159]. The energy content of methane described by the Lower Calorific Value (LCV) is 50.4 MJ/kg CH_4 or 36 MJ/m^3 CH_4 (at STP conditions). Therefore, the higher the CO_2 or N_2 content is, the lower the LCV in biogas [11, 160]. Developing the quantity and quality of biogas often needs pretreatment to maximize methane yields and/or post-treatment to take out H_2S, which includes higher costs and considerable energy consumption. Therefore, scientific research has performed to develop a low-cost desulfurization process and improve AD conversion. Appealingly, there are a lot of techniques that have been approved to enhance the anaerobic digestion process, like pretreatment procedures using acidic/alkaline, ultrasonic, thermal methods [161–163]. Lately, there are various treatments targeting at get rid of the trace contaminants and undesired components from the biogas expanding its range of applications [11]. Biomethane involves two major treatment processes; cleaning and CH_4 enrichment (biogas upgrading). The cleaning of the biogas contains elimination of impurities and acidic gases; whereas, the enrichment process is for extraction of CO_2 from biogas [11, 96]. There are three major reasons for gas cleaning;

fulfill the requirements of gas appliances (gas engines, boilers, fuel cells, vehicles, etc.), increase the heating value of the gas, and standardization of the gas [58]. Biogas cleaning treatment process includes removal of undesired materials (such as, NH_3, siloxanes, H_2S, volatile organic compounds (VOCs), and CO) to increase the quality of biogas. However, it is practically only H_2S which is mainly targeted and many current biogas plants have H_2S elimination units normally rely on biological H_2S oxidation by aerobic sulfate oxidizing bacteria [11]. Biogas must be desulfurizated and also dried before usage to stop destroys the use of gas units. The concentration of H_2S between 100 and 3000 ppm in biogas generated by cofermentation of manure with harvesting debris or energy crops, in order to prevent an expensive deterioration of lubrication oil and excessive corrosion [21, 22]. CHPs are used for the utilization of biogas need generally levels of H_2S below 250 ppm. The existence of H_2S not only affects the quality and quantity of the biogas generated which can restrict its application, but also produces dangerous environmental emissions and corrodes the motors of biogas purification machinery [20, 23]. Nowadays, biological desulfurization process mainly used to remove of H_2S [21, 22]. Recent study conducted by Register Mrosso [164] reported that red rock (RR) is an available material for biogas purification which used to remove hydrogen sulfide from biogas [164]. The quality of raw biogas can be further improved via various upgrading techniques to remove the non-combustible components and as a result increasing the methane content to approximate natural gas quality (75–98% methane) [96]. Biogas has been upgraded to natural gas composition via methanation using renewable hydrogen [165]. The higher the methane content, the richer the biogas is in energy [12]. Biogas upgrading aims to increase the low calorific value of the biogas, and convert it to higher fuel standard [35]. In case the upgraded biogas is purified to specifications similar to natural gas, the final gas product is called biomethane [11, 166]. Biomethane is a gaseous fuel with physicochemical properties similar to those of natural gas, which makes it possible to inject it into the gas grid [96]. Currently, the specifications of the natural gas composition are depending on national regulations and in some countries >95% methane content is required [11].

Technological development plays an important role in biogas upgradation and purification processes in large-scale commercialization of biogas. There are various cleaning and upgrading techniques to improve the quality of raw biogas which can be categorized into physiochemical and biological technologies. Some of these techniques are conventional methods, including physical absorption, chemical absorption, membrane infiltration and biological methods, and others are considered as new technologies including cryogenic upgradation, membrane enrichment, multistage-, and high-pressurized AD [62, 96, 167, 168].

Physiochemical technologies for cleaning of biogas and its subsequent CH_4 enrichment can be grouped as follows: absorption process (physical and chemical absorption), Hybrid solution (mixed physical and chemical solvent), and physical separation (adsorption on solid surface; membrane; cryogenic) [96]. Novel technologies, such as cryogenic separation, in-situ upgrading, hydrate separation, and biological methods, represent the recent developments in biogas upgrading technologies. Biogas can be used as fuel for domestic stoves, boilers, internal engines, gas turbines, cars, and fuel cells, or injected into natural gas grids to replace gaseous fuel [35]. These techniques have been reported to yield biomethane typically containing 95–99% CH_4 and 1–3% CO_2. At this quality, the spectrum of applications for biogas widens, it can be used to serve the same applications as natural gas [96]. Gas upgrading and utilization as renewable vehicle fuel or injection into the natural gas grid is of increasing interest because the gas can be used in a more efficient way [21]. Types of upgrading plants are available in Sweden, and shows that around 70% of the biogas purification plants apply water-washing technologies [169].

6.1 Physiochemical technologies include

6.1.1 Physical absorption method

Physical absorption method uses water scrubbing system. Water scrubbing is the most commonly used technology for biogas cleaning and upgrading [170].

This process depends on the extraction of H_2S and CO_2 from the biogas because of their raised solubility in water compared to CH_4 (i.e., according to Henry's law, the solubility of CO_2 in water at 25°C is roughly 26 times higher compared to methane); whereas, physical absorption method is using organic solvents. This method relies on the same principle as water scrubbing; however, the absorption of CO_2 and H_2S is accomplished by the use of organic solvent instead of water.

6.1.2 Chemical absorption method

Various methods are used to bind the CO_2 molecules contained in the biogas, such as chemical scrubbers, utilize aqueous amine solutions (i.e., mono-, di-, or triethanolamine); chemical absorption method; and using amine solutions. One of the benefits of this technology is that H_2S can be totally absorbed in the amine scrubber. Amine scrubbing systems mostly contain a stripper and an absorber unit.

6.1.3 Pressure swing adsorption (PSA)

Pressure swing adsorption (PSA), which extracts the various gasses from biogas, relies on their molecular properties and the compatibility of the adsorbent matters. The adsorbents can be zeolites (Zeolite 13X, Zeolite 5A), carbon molecular sieve, activated carbon, and other substances with high surface area [171]. The major principle of PSA system depends on the properties of pressurized gasses to be appealed to solid surfaces. Thus, under high pressure, huge quantities of gas will be adsorbed, whereas, a decline of pressure will result in gas discharge. The PSA technology follows four different or equal duration stages, namely pressurization, adsorption, blow-down, and purge [171].

6.1.4 Membrane technology

Membrane technology is considered as an alternative to the traditional absorption-based biogas upgrading technology. The major principle of the membrane technology depends on the selective permeability characteristics of membranes allowing the biogas components to separate [172].

6.1.5 Cryogenic technique

The bases of this technology are the different liquefaction temperatures for biogas compounds [173]. It is conducted through a gradual decrease of biogas temperature allows the selective separation of CH_4 from both CO_2 and rest components. Thus, a high-purity biomethane is obtained in agreement with the quality standards for Liquefied Natural Gas (LNG). The easiest path to remove the impurities contained in biogas by means of cryogenic methods employs a constant pressure of 10 bar [9, 174–176]. The liquefaction is carried out by declining the temperature successively in order to get rid of each pollutant or mitigate them in different steps. The first step is often set up at −25°C, where mostly siloxanes, H_2O, and H_2S are obtained. A second set step is assigned at −55°C to partially liquefied CO_2, accompanied by a new decline until −85°C to totally get rid of the remaining CO_2 by a solidification step [177]. The liquefied CO_2 gained in the second temperature stage can be sold as high-purity by-products to improve the whole economic process performance. Another more normally used option contains a preparatory dry of the gas accompanied by a multistep compression up to 80 bar. This permits preserving a higher operational temperature of between −45 and −55°C, containing as major drawback a needful intermediate cooling in the multistep compression [178]. Cryogenic techniques represent a good option to be optimized because these techniques yield high-purity products, ranging between 95 and 99% [13, 179].

6.1.6 Chemical hydrogenation method

The reduction of CO_2 with H_2 can be either conducted biologically or chemically, based on Sabatier reaction. Regarding the chemical hydrogenation process, various catalysts, with Nickel and Ruthenium to be the most commonly used in industrial applications have already been tested under elevated temperature (e.g., 300°C) and pressure levels (e.g., 5–20 MPa) [180, 181]. Due to high selectivity, complete conversion of CO_2 and H_2 can be practically achieved [182]. Nevertheless, despite the high process efficiency, specific drawbacks still remain. For instance, the sustainability is affected by the presence of trace gasses in the biogas, which degenerate the catalysts leading to increased need for periodical replacement [183]. The high cost of energy to preserve the operational conditions, the lack of elements to synthesize effective catalysts, and the need for pure gasses are further technical challenges of the system [11].

6.2 Biological technologies

The biological biogas upgrading technologies are classified into chemoautotrophic and photosynthetic. Most of these configurations have been practically proven and are at an initial step of pilot or full scale application. The main benefit of such techniques is associated to the fact that the CO_2 is transformed into other energy containing or valuable added products at mild operational conditions (i.e., moderate temperature levels, atmospheric pressure) contributing extremely to a circular economy and sustainable bio-based.

6.2.1 Chemoautotrophic techniques

The chemoautotrophic biogas upgrading techniques rely on the action of hydrogenotrophic methanogens that can use H_2 to transform CO_2 to CH_4 depending on the following equation:

$$4H_2 + CO_2 \rightarrow CH_4 + H_2O \ \Delta G^\circ = -130.7\,kJ/mol \quad (4)$$

But, in order to make the biological upgrading technology renewable, the necessary H_2 in the reaction has to be extracted from renewable source. Thus, the using renewable electricity concept for generation of H_2 by hydrolyzing water has attracted great attention, particularly in cases that residual electricity from solar panels or wind mills is exploited. Whereas, in the concept of in-situ biological biogas upgrading, H_2 is injected into a biogas digester in order to be connected with the endogenous CO_2, which is generated in the anaerobic reactor and be transformed into CH_4 by the action of autochthonous methanogenic archaea [11, 166].

6.2.2 Photoautotrophic methods

The photosynthetic biogas upgrading is an alternative technology to isolate the CO_2 in order to produce a CH_4-rich gas. By performing these techniques, H_2S elimination is further achieved; whereas, >54% of CO_2 is devoured. The methane recovery of photoautotrophic methods can reach up to roughly 97% relying on the reactor kinds and the selection of algal species.

Physicochemical methods are in general at high technology readiness levels, while biological methods are still new and not commercial yet. However, they offer huge potential in respect to feasibility, technological easiness, and potential. Biological upgrading opens new horizons for integrating different forms of renewable energy and besides upgrading can offer electricity storage advances and decoupling bioenergy production from biomass availability [11].

7. Biogas applications

Biogas generation serves three important functions: waste removal, environmental management, and energy production [12]. The first and most direct use of biogas is for heating and domestic purposes [184]. Biogas is an excellent fuel with a numerous application [62]. Biogas that is purified and enriched in methane can be used for household applications, automobile fuel (liquefied), or electricity generation [185, 186]. The biogas is mostly utilized as a combined heat and power (CHP) application in the overall world; and apart from it, it can be used in three sides such as fuels for cars, steam generation, and electric power. Biogas obtained from renewable organic waste is counted as an alternative energy for nonrenewable fuels due to its broad applications in fuel and transportation sector [62, 104, 187].

In general, Waste-to-Energy (WtE) technologies can be defined as any waste treatment processes that create energy from a waste source in any forms of energy carrier, i.e., electricity, heat, or transportation fuels [188]. Depending on a statement by World Energy Council, restricted landfilling capacities, rise in the quantity of produced waste, high costs of energy, and rising concerns of environmental issues are the summarized major factors for the growth in WtE market in the past decades. In 2013, the international WtE market encountered a growth of 5.5% and reached a value of 25.32 billion USD with respect to its previous year [50, 188]. Biogas is a flexible energy transporter, appropriate for various applications. One of the simplest applications of biogas is the immediate utilization for lighting, and cooking, but in a lot of countries biogas is currently utilized for combining heat and power generation (CHP) or it is upgraded and fed into natural gas grids, utilized in fuel cells or as car fuel [189]. Biogas is appropriate for production of electricity in combination with heat recovery. Normally, the gas is combusted in motors with internal combustion connected to turbine. The discharged heat (being about 60% of the used energy) is utilized for heating purposes for household requirements or maintenance of the anaerobic reactor. This method is broadly used for the treatment of activated sludge, debris generated from municipal wastewater treatment plants [184, 190, 191]. Electric power generation by gas turbines can be used by biogas as a fuel, hence substituting the natural gas for small-scale applications [184]. There is a large demand to make biogas transportable. This can be simply done only after taking out impurities such as CO_2, H_2S, and water vapor by compressing and filling the cylinders in it after scrubbing and drying processes [185]. Elimination of carbon dioxide from the flue gas assists to get fuel of higher calorific value as well as to remove the GHG [185, 192]. Biogas is an encouraging renewable source of energy. It can be immediately transformed into electricity, e.g., in a fuel cell, or burnt, discharging heat at high temperature, or burnt in a CHP for the simultaneous generation of heat and power, or fed into the natural gas network for energy rescuing purposes or it can used as fuel for cars, being sold by gas stations. Mostly, the biogas should be transported over long distances and must be purified before further utilization [18]. Biogas systems turn the cost of waste management into a revenue opportunity for farms, dairies, and industries. Converting waste into electricity, heat, or car fuel provides a renewable source of energy that can reduce dependence on foreign oil imports [189]. Biogas is mostly used in factory boilers and in engine generator sets to produce electricity and heat. In those cases, where an internal combustion engine is fuelled with biogas to produce electricity, the electricity can either be used by the facility itself or transferred to a local or national power grid [12]. The most profitable way to use biogas may be to convert it into natural gas. In reality, biogas can be utilized in all applications created for natural gas. The major difference between the two fuels is that, further to methane, natural gas consists of a variety of other hydrocarbons, like propane, butane, and ethane, which provide it a higher calorific value than pure methane. Biogas is normally burned in internal combustion motors to produce electric power. An electrical conversion efficiency of up to 25% can be obtained via small-scale internal combustion motors, with a rated capacity of less than 200 W as well as much higher electrical conversion efficiencies, of 30–35% can be provided through larger internal combustion motors (up to 1.5 MW). When biogas is utilized to generate electric power, there is the extra potential for heating water from the engine's exhaust and cooling systems. Combining hot water generation with electric power production can provide total conversion efficiency as high as 65–85%. An encouraging near-future application for electric power production is the utilization of gas turbines. Combined-cycle power stations are made up of waste heat recovery boilers, gas turbines, and steam turbines that function together to generate electric power in the larger-scale systems. Advanced gas turbine plants tend to be small, environment friendly, greatly efficient, and visually unobtrusive. Units as small as 200 kW are not uncommon, but only those greater than 800 kW have electrical conversion efficiencies that equal or surpass an internal combustion engine-based system. Gas turbines allow a greater fraction of waste heat to be recovered as steam, a critical commodity for many industries, so overall efficiency levels for gas turbines can be up to 75%. Recently, biogas applications are employed as fuel in fuel cells and as fuel for micro-CHP (combined heat and power). When connected with an organic Rankine cycle (ORC) turbine, a biogas-powered CHP can raise electrical efficiency by 8–10%, making total efficiency rate of 45–48% more than reasonable [12, 184]. Another very attractive application of biogas for electricity production is its use in fuel cells. The specialized cells for these purposes are described briefly by [193]. Identical efficiency rates are obviously being accomplished with biogas fuel cell technique. Sweden-based Acumentrics Corporation, for instance, has registered improved performances with its 5000 W fuel cells, known as solid oxide fuel cell (SOFC) systems, which work on biogas rather than hydrogen, which is difficult to handle, high cost, and difficult to store [12]. The utilization of biogas as a fuel for civil transport and road cars in place of natural gas is already widen in United States and Western Europe [194]. There are a lot of automobiles in Sweden turning on biogas in the urban public transport [184, 195]. Biogas is currently used in many developing countries as an alternative and renewable source of energy for wide spread range of applications. In contemporary times, biogas has been used most extensively in India and China. The Biogas Association in Germany, the world's largest producer country, included the three functions in its recent summary of what it called the national benefits of biogas production: 650 MW of installed electrical capacity comes from biogas, a reduction of 4 million tons per year of CO_2 emissions, revenues of $500 million for biogas farmers from electricity sales annually, and use by the AD process of biomass material that would otherwise end up in landfills. Economic production of biogas can be economically achieved for both large- and small-scale applications. Hence, it can be designed to fit into rural, urban, as well as regional and nationwide energy needs making it a versatile source of energy [12, 96, 107]. All over the world, Europe has registered the highest growth of biogas utilization with a notable 18% raise registered between 2006 and 2007. Sweden and Germany have registered the highest growth levels with Germany leading to brag over 4000 biogas plants, most of them are established on farms for electric power and heat co-generation [21, 96].

In Sweden, there is currently great interest in the biogas process, since it can stabilize and reduce various types of organic waste while producing renewable and environmentally friendly energy in the form of biogas. There is also increasing interest in both the production of biogas from municipal sewage treatment plants and on-farm biogas production within agriculture [196]. Biogas is also burned in boilers to produce hot water and steam in a variety of settings, including hotels, warehouses, factories, schools, prisons, and other public buildings. The forest-product segment is perhaps the largest user of biomass (combustion) energy in the industrial sector. In addition, in many countries, biogas is viewed as an environmentally attractive alternative to diesel and petrol for operating busses and other local transport vehicles [12]. The food and drinks industries are the largest users of AD for wastewater pretreatment. In 2006, 3400 GW of biogas power was generated in Germany, equivalent to 0.6% of the country's total energy consumption, reducing carbon dioxide emissions by 2.5 million tons. Countries such as Sweden is considered pioneered in the utilization of upgrading biogas as a light duty car fuel, and the use of biogas in the country has already exceeded natural gas [12, 197]. Identical attempts are also being made in Germany which presently turns on roughly 5000 anaerobic reactors for generation of bioenergy [198]. In the UK, fears over the utilization of biogas as fuel stem from an insufficiency of quality standards and infrastructure, as well as contest with other utilizes of biogas [199, 200]. At the moment, close to 50 biogas plants, mainly small, farm-scale ones, are in operation in Austria, Currently, around 25 biogas plants operate in Denmark, with capacities ranging from 50 to 500 tons of biomass feedstock per day. The resulting biogas is mainly used in heat and power generation applications, while the digested biomass is redistributed to farms as fertilizer. Swedish company Svensk Biogas has developed a passenger train that runs exclusively on biogas. The train has a range of 600 km and can attain speeds of 130 kph. There are also up to 100 municipal busses running on biogas. The Swedish agricultural sector is also increasingly using the residues from the anaerobic digestion of crops and clean organic waste in order to return nutrients to the soil and reduce its dependence on mineral fertilizers. Biogas can also be used to generate electricity alone or with heat (co-generation). Biogas can also be used, like pure methane, as a fuel for motor vehicles [12, 201]. Biogas can be considered as alternative green energy carrier for harnessing electricity, heat, and as a transport fuel [62, 202]. Biogas is a renewable source of energy that can be used as a substitute for natural gas or liquefied petroleum gas. Biogas is a clean, efficient, and renewable green source of energy, which can be used as a substitute for other fuels in order to save energy in rural areas [86, 203, 204]. A series of zero-waste technologies are presented. They are similar to the "five zeros" of the Olympic logo which are zero waste in the product life cycle, zero emissions, zero waste in activities, zero use of toxics, and zero resource waste. This design, firstly invented by Lakhal and H'Mida [205] was titled the Olympic Green Chain model. Lately, Khan and Islam [206] suggested a method for zero-waste (mass) utilization for an ideal urban setting, involving processing and regeneration of gas, liquid, and solid. In this process, kitchen sewage waste and waste are used for diverse purposes, involving generation of biogas, water heating from flue gas, good fertilizer for agricultural production and desalination. The carbon dioxide produced from biogas burning is used for the desalination plant. This process gets zero-waste in mass utilization. The technology development in this line has no negative impact on global warming. It is estimated that biogas usage in the world will be doubled in the coming years, increasing from 14.5 GW in 2012 to 29.5 GW in 2022 [37, 189, 207].

8. Advantages and limitations of biogas technologies

Biofuels are produced from biomass for a wide range of applications, such as cooking, heating, cooling, and transport. Biofuels can be solid (e.g., fuel-wood), liquid (e.g., bioethanol, biodiesel) or gaseous (e.g., biogas) [208, 209]. Biogas technology utilizes organic wastes for energy production, followed by recycling of the digested substrate as fertilizer [189]. Biogas can be used to generate heat or electricity, or as fuel for manufacturing or transport [210]. Electrical energy and heat generation from biogas is a source of green, environmentally friendly energy. At the same time, there is a reduction in methane emission from the decomposition of unmanaged biomass (especially animal droppings) [211–213]. Main benefits of biogas technology are to transform waste material into a valuable resource thus reducing waste, and providing valuable green energy [86, 189].

8.1 Advantages of biogas technologies

The production of biogas through anaerobic digestion (AD) offers significant advantages over other technologies of bioenergy production. It has been acknowledged as one of the most energy-efficient and green technology for bioenergy production [82]. For many reasons, it is a versatile renewable energy source [158], it can be produced when needed and can easily be stored [61], biogas can be easily upgraded to remove undesired components thus producing a higher fuel standard (Biomethane) with high specific caloric value [189]; it combines energy (gas) storage with generation [214]; the feedstock source is often a waste or problem product, and hence its use for energetic utilization resolves waste management problems [214]; biogas technology provides an excellent opportunity for mitigation of greenhouse gas emission, improving air quality, and reducing global warming [6, 215–217]. Biogas technology also has potential to mitigate climate change and eutrophication [218]; it can be used as an alternative to fossil fuels [158]; it can easily co-digest a range of feedstocks, thus providing an integrated waste management service; it provides valuable co-products such as nutrient-rich bioslurry [214]; biogas production is a treatment technology that generates renewable energy and recycles organic waste into a digested biomass, which can be used as fertilizer and soil amendment [82, 189]; Methane-rich biogas (biomethane) can also replace natural gas as a feedstock for producing chemical materials [82]; biogas is considered to be the future of renewable and sustainable energy [219]; noise levels generated by methane-powered engines are considerably lower than those of diesel engines, a plus in congested urban environments [12]; biogas technology has an important role to play in the waste management, renewable energy, water, and nutrient (food security) sectors [214]. The development of a national biogas sector contributes to increase the income in rural areas and creates new jobs [189].

The benefits of using co-digestion techniques for optimizing biogas production yields which including dilution of potential toxic compounds, improved balance nutrients, synergistic effect of microorganism, increased load of biodegradable organic matter, and higher biogas yield [82, 220, 221]. In small-scale installations, worldwide, the gas is primarily utilized for lighting and cooking. In larger units, the gas can be used for co-generation (generation of heat and electricity), as vehicle fuel or as fuel in industrial processes [58].

8.2 Disadvantages and problems

Biogas production from anaerobic digestion (AD) suffers from several technical limitations. The social acceptance of biogas is usually hampered by health and environmental concerns. There are undesired and harmful substances contained in biogas which considered as biogas pollutants (such as H_2S, Si, volatile organic compounds (VOCs), siloxanes, CO, and NH_3). H_2S and NH_3 are toxic and extremely corrosive, damaging the combined heat and power (CHP) unit and metal parts via emission of SO_2 from combustion [11, 160, 215]. The existence of H_2S not only influences the quantity and quality of the biogas produced which can limit its application, but also generates harmful environmental emissions and corrodes the engines of biogas purification machinery [23, 163]. It also causes excessive corrosion and expensive deterioration of lubrication oil [21]. Moreover, the presence of siloxanes in biogas, even in minor concentrations, is associated with problems. It is well known that during combustion silicone oxides generate sticky residues, which deposit in biogas combustion engines and valves causing malfunction [11, 160]. Biogas produced by AD still contains impurities. Therefore, the systems used in the production of biogas are not efficient [189]. The quality and quantity of biogas usually requires pretreatment to maximize methane yields and post-treatment to remove H_2S, which involves considerable energy consumption and higher costs [163]. There are no new technologies yet to simplify the process and make it abundant and low cost. Similar to other renewable energy sources (e.g., solar, wind) production of biogas is also influenced by the climate. The optimal temperature required for bacteria to digest waste is about 37°C. In cold weather, digesters need heat energy to preserve a fixed biogas supply [189]. The greatest challenge encountering the utilization of biogas as a truck and bus fuel has been the restricted driving range that it provides, meaning that drivers must refuel much more often than they would in petrol- or diesel-powered cars [12].

9. Laws and guidelines concerning biogas plants

Most countries are in the process of instituting legislation to regulate the biogas industry [12]. Mostly, all parts of the plant must be checked out and licensed by the authorities. This involves installations such as tanks for liquid manure, bioreactors, gasholders, ignition oil tanks, stores, and combined heat and power stations (CHP). In biogas plants, the formation of explosive gas mixtures can happen. Thus, a system for plant security has to be present relating to installation and operation of electrical instruments in regions with high risk of explosions [18].

In Africa and the Middle East, the alternative energy market is new, so there are few government regulations and formal incentives. With inexpensive and abundant energy sources—coal in South Africa and oil in the Middle East—interest on the part of the state sector in renewable energy has been minimal. Although there are few laws or regulations pertaining to the biogas sector—reflecting the undeveloped state of the industry, due primarily to abundant and inexpensive sources of traditional fossil fuels, which gives little or no incentive to look for alternative energy sources, South Africa is leading the way in the region.

The South African Minerals and Energy Department, for instance, published its energy efficiency and renewable strategy statement in 2006, which involved statements and targets on biogas. These involved a "target requirement" to generate 4% nearly 10,000 GWh of the country's electric power from renewable sources in 2013. In some of African countries, involving Egypt, South Africa, and Morocco, there are disagreement of interest over who has the lawful right to utilize municipal and common, specially maize (corn), or tribal, land to cultivate biogas crops [12].

In Europe, legislation is well developed, reflecting the relatively high level of biogas production in many EU markets, such as Germany and the UK, where biogas is the fastest-growing segment of the renewable fuels industry [12]. Europe is the most advanced biogas market in the world and legislation is much more developed than in other regions, with laws and regulations that not only relate to requirements to treat organic waste in certain ways, but also reach an unusual level of detail regarding machine, plant, and process specifications [18]. The European Commission is proposing an increase in the use worldwide of renewable energy sources to 20% of the total demand, which would limit global temperature changes to no more than 2°C above pre-industrial levels. The Commission has stated, rather vaguely, that it seeks, via both voluntary and legal means, to improve the EU's energy efficiency by 20%, in order to "make the EU the most energy-efficient region in the world" [12].

In Germany, there are a lot of state laws, regulations, norms, and guidelines of branch institutions were released in order to preserve a secure and smooth biogas plants operation. These cover their waste management, installation, operation, and supply. A lot of offices are included in managerial decision for the a plant construction, e.g., the office for noise control-traffic-energy-climatic protection, the planning department and building control office, the water regulatory authority, the natural conservation authority, food control, the authority for nutrition, the authority of agriculture, the office for veterinary matters, the office for technology and plant safety, the public order office, etc. [18]. In Germany, for instance, biogas is the fastest-growing segment in the alternative energy industry. Thus, both local and national governments are beginning to oversee the sector at a much more detailed level than before. Laws requiring more cooperation between biogas producers and public utility companies, to avoid electrocution of workers who may shut down power to an electric cable but the farm-based generator continues to feed energy into it, have come into force in most states since 2006. Most states now have laws requiring electricity utilities to buy excess biogas production, either via established gas distribution networks or directly through national pipelines. EU energy vision includes a cut in carbon dioxide emissions by at least 20% by 2020 [12]. The German law of biowaste biomass specifies the biomasses and the technical processes supported. Approved biomass consists of pure herbaceous products. Not approved are fossil fuels, mixed wastes, mud, sewage sludge, and port sludge.

Debris from biogas plants are undergo to the German law of fertilizers, involving when domestic waste water undergo fermentation or when it is blended with agricultural substrates. The German law of fertilizers control single guidelines like temporary permissions to use fertilizer, the determination of fertilizing requirements, the maximum limits for the utilized amount of fertilizer, methods to use, and much more. The given name of these regulations is the "principles of the good and professional execution of fertilizing." In Germany, no liquid secondary raw material fertilizer or liquid manure are permitted to be utilized from November 15th to January 15th. This is due to the soil is chilled and the product of fermentation cannot go through the soil. The distribution of debris from biogas plants is also managed. Maximum amount of total nitrogen from industrial fertilizer are allowed on pasture land is not more than 210 kg/ha.a and on ground used agriculturally is not more than 170 kg/ha.a. For phosphates, 120 kg/ha.a as maximum limits for both on pasture as well as on ground used agriculturally, for calcium the limit is regulated to 360 kg/ha.a. Farms with greater than 10 ha of ground utilized agriculturally are compelled to make a written fertilizer balance to keep track of their utilization [18].

In biogas plants, substances able to contaminate water are treated. In most countries, it is banned by law to contaminate water. Best available measures have to be taken in biogas plants to preserve water from pollution. The distribution of debris in agriculture should be done as stated in specified techniques [18].

In North America, the main US biogas legislation is the Biogas Production Incentives Act of 2007. A widespread unwillingness on the part of electricity companies in both the US and Canada to cooperate with biogas farm-scale producers has discouraged the development of the biogas sector. In response, many states are introducing legislation to oblige electricity providers to work with biogas producers and to buy any excess electricity. Electricity utilities, though, are generally unhappy with the arrangement, as the electricity produced by the biogas plant to run the farm is considered by them to be lost revenue. In Canada, the electric power prices provided to farmers generating biogas are still not enough to make production feasible. The Standard Offer Contract (SOC) program lately launched in Ontario, though, whereas not providing immediate financial inducements, is a first stage in the direction of promoting biogas generation though the utilization of energy crops and anaerobic reactors [12].

In Latin America, laws on quality standards for agricultural and organic waste are now being introduced, although in most cases these have not yet been clearly defined. Governments are only now beginning to make use of tax and investment incentives to encourage production. Latin America Argentina, Brazil and Colombia have the most developed legislative frameworks for the biofuels industry overall, each having set minimum requirement levels for the percentage of renewable fuels in petrol, diesel oil, and fuel oil. In Argentina, for example, the Biofuels Act of May 2006 was the first law to grant tax incentives to alternative fuel producers. The law will initially be in effect for 15 years. It stipulates that biogas can be produced from raw materials in the agricultural, agro-industrial or organic waste sectors provided they meet the government's quality standards which have yet to be clearly identified [12].

In Asia, Asian governments are beginning to encourage the biogas sector, basically by providing financial and legal incentives to produce energy from organic waste sources in large municipal waste dumps, the existence of which is coming under heavy local opposition in many cities. In India and Mongolia, household and industrial waste laws were legislated in early 2007, requiring the separation and treatment of both kinds of waste at an early processing stage, with a view to using organic and biodegradable waste for energy production. Recently, the Indonesian government issued a statute requiring minimum levels of biogas production from new waste disposal sites that are under construction. The way in which the gas is produced, whether it be by composting, landfill, or anaerobic digestion, can be selected by the producer [12].

10. Conclusions

Most of industrial and chemical processes produce wastes. Raw materials for producing biogas by anaerobic digestion are biomass feedstocks which include; municipal solid waste (MSW), industrial solid wastes and industrial wastewaters, food waste, livestock manure, sewage sludge, agricultural manures, catch crops, energy crops, and microalgae. Biogas production serves three important functions: waste removal, environmental management, and energy production. Biogas is a versatile renewable green energy source, which can be used for replacement of fossil fuels in power and heat production, and as gaseous vehicle fuel. Biogas technology is considered an alternative green energy resource. The use of energy and manure can lead to social economic benefits, green environment, and also contributes toward sustainable development. Renewable energy technologies provide an excellent opportunity for mitigation of greenhouse gas emission and reducing global warming through substituting conventional energy sources. Anaerobic digestion of organic waste is the most desirable management method, and this research discussed it in detail. There are undesired compounds and other gases contained in biogas which are considered as biogas pollutants. Improving the quality and quantity of biogas usually requires pretreatment to maximize methane yields and/or post-treatment to remove H_2S. The pretreatment of organic waste is the key process step in biogas production plants. Biomethane involves two major treatment processes; cleaning and CH_4 enrichment (biogas upgrading). The cleaning of the biogas consists of removal of acidic gases and impurities, while the enrichment process is for separation of CO_2 from biogas. It is noted that, there are different kinds of digesters, typically digester type is to be selected depending on the characteristics of the major feedstock used, particularly total solid. The study also concluded that, there are various cleaning and upgrading techniques to improve the quality of raw biogas which can be categorized into physiochemical and biological technologies. Some of these techniques are conventional methods, including physical absorption, chemical absorption, membrane infiltration, and biological methods, and others are considered new technologies, including cryogenic upgradation, membrane enrichment, multistage-, and high-pressurized AD. Novel technologies, such as cryogenic separation, in-situ upgrading, hydrate separation, and biological methods, represent the recent developments in biogas upgrading technologies. The biological biogas upgrading technologies can be classified into chemoautotrophic and photosynthetic. Physicochemical methods are in general at high technology readiness levels, while biological methods are still new and not commercial yet. It is reported that, most countries are in the process of instituting legislation to regulate the biogas industry. Europe is the most advanced biogas market in the world and legislation is much more developed than in other regions. Biogas is considered to be the future of renewable and sustainable energy.

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