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Biomass as an Alternative for Gas Production

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Additional information is available at the end of the chapter

<http://dx.doi.org/10.5772/67952>

Abstract

Natural gas comes from the decomposition of organic material under anaerobic conditions in a process that occurred around 150 million years ago, which allows the gas trapping between rock pore spaces (porous system). Even though natural gas has become one of the most used fuels around the world, there are other spontaneous, continuous, ongoing, or inducing processes that can produce a similar gas in a short time (considering human scale); we refer to biogas. The aim of this chapter is to describe the biomass potential from organic residues for biogas production. The first part explains the biomass as an energy source, a comparison between natural gas reserves and sources of biogas with a global perspective of their energy contribution. The main biomass conversion technologies followed by case studies are shown in the second part. Finally, the biomethanization process is covered as a promising way to valorize some biomass residues into natural gas. Information about where and how the biogas can be contained, controlled, and distributed is provided. This chapter focuses in considering biogas as an alternative in the fuel demand with the advantage of coming from a renewable source, providing electricity, heat, or transport, and the generation of by-products.

Keywords: organic residues, biomass conversion, biomethane, biogas, renewable energy

1. Introduction

Nowadays, the impact of the climate change around the world is undeniable. Most of the environmental, social, and economic problems that all societies face are associated to the

energy consumption and water demand, as well as other services. Crude oil and natural gas have been used for decades, the main energy source in the major economies. Nevertheless, it has been proved that the majority of anthropogenic greenhouse gas (GHG) emissions account to the consumptions of these fossil fuels [1], increasing the global warming.

The concern is not only about the negative impacts on environment; it is also the dwindling of the fossil fuel reserves. This situation is disquieting and has focused the world's attention on the search and adoption of alternative energy sources. One of them, in this case study, is biogas production. The latter is one of the biofuels in gas form that are made from biological sources and brings an option for sharing the energy demand through the treatment of some biomass residues.

In this perspective, this chapter focuses on the description of biogas production through the use of biomass with the adoption of biological technologies as a promising way for contributing the safe and sustainable energy supply, providing heat, electricity, and biomethane (similar to natural gas).

2. Biomass as an energy source

Energy is manifested by heat or electricity that is derived from fossil fuels. In some countries, not only fossil fuels can be used for this goal; there are other elements like some plants, agricultural residues, and municipal organic wastes that can also provide it.

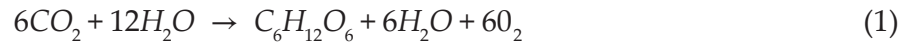
As the law of conversation of energy states, “energy can neither be created nor destroyed; it can only be transformed from one form to another.” For instance, the chemical energy stored in some organic residues can be converted to other forms of energy.

This is exactly what the bioenergy look for: the use of the stored energy from organic materials. Here is where the concept of *biomass* is introduced as a raw organic material that can be treated to generate heat and electricity from liquid, solid, or gaseous biofuels. In this respect, biomass resources represent a biogas production source. It is also one of the most abundant resources and comprises all biological materials including living or recently living organism and is considered a renewable organic resource [2].

The biomass resources take their energy from the sun, as most of the other renewable energies sources. For example, photovoltaic energy captures the solar radiation in a direct way by specialized equipment providing energy. Also, the solar energy that is transferred through the space causes the moving of air masses by heating results in wind, which can be used through turbines and generates electricity. Energy is also transferred to the water flows. The precipitation of water vapor due to the combination of wind and heat from solar energy causes the rain, which turns rivers on. The force of the water flow also can be exploiting to produce energy (hydroelectricity) and so on.

Energy from biomass is not the exception. The so-called bioenergy can harness solar energy stored in various biomass resources. Plants, for example, use solar energy to convert inorganic compounds assimilated into the organic compounds (Eq. (1)).

Photosynthesis process:



An animal that eats plants takes advantage of the stored energy from these and generates biomass. Biomass works as a type of storage (battery) of solar energy transferred from one trophic level to another. The transfer of energy is evident in all processes of living beings (Figure 1).

Around the world, there are different sources of biomass which can be used for its conversion into energy, which includes material of biological origin, like living plants and animals and resulting residues, crops and forestry residues, sea weeds, agro-industrial residues, sewage, and municipal solid waste. Biomass can be almost all the organic material, excluding fossilized organic material embedded in geological formation [3].

Most of these biomass resources represent an environmental problem if they are not managed, transported, or disposed properly. Consequently, if energy is generated by the use of them, we can contribute for reducing the environmental pollution [4]. Furthermore, this source of energy has the advantage of not releasing CO_2 into the atmosphere due to the carbon capture and storage, serving as an effective carbon sink [2].

Moreover, biomass can be multiplied in different forms of energy, that is, heat from wood and forestry residues, chemical energy from hydrogen and some biofuels, and electrical energy from the use of biogas in certain motor engines. In this chapter, we will focus in biogas, which represents a biofuel generated by biomass conversion technologies (anaerobic digestion) and an alternative for gas production.

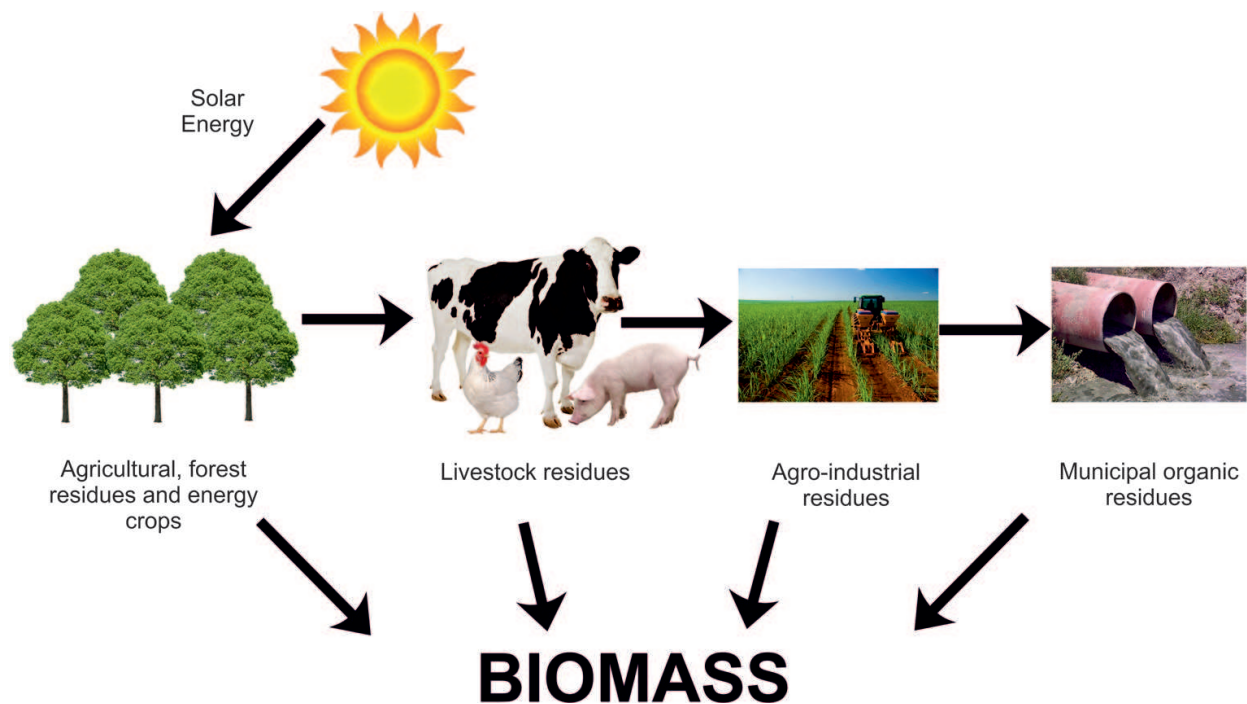


Figure 1. Energy from different biomass sources.

2.1. Is biogas the same as natural gas?

The answer is no. Natural gas comes from the decomposition of organic material under anaerobic conditions but was exposed to intense heat and pressure, in a process that occurred around 150 million year ago, which allows the gas trapping between rock pore spaces (porous systems). The gas produced during this period of time is located various meters below the surface of the earth. It is not considered a renewable resource. The process for natural gas production considers mainly extraction from the subsurface, collection, treatment, transportation, and distribution services.

On the other hand, biogas is the term employed to refer to the gas obtained in a short time (considering human scale) by the anaerobic digestion of biomass resources. The process occurs sometimes as a spontaneous, continuous, ongoing, or inducing way but always is very sensible to biological process. Indeed, specific microorganisms, in a four-step process (hydrolysis, acidification, acetogenesis, and methanogenesis), achieve the anaerobic digestion of organic material (**Figure 2**). To do so, certain physico-chemical parameters such as temperature, pH, daily organic load, available nutrients, retention time, agitation, and other inhibitory factors must be adequate or adjusted for generating biogas [5].

The main difference between natural gas and biogas is related to the carbon dioxide content. The latter is contained in 25–45% of the total composition of biogas, while natural gas contains less than 1% (**Table 1**). Moreover, natural gas contains other hydrocarbons rather than methane. The methane content strongly influences the calorific value of these gases. Energy content of biogas similar to natural gas can be obtained if carbon dioxide from biogas is removed

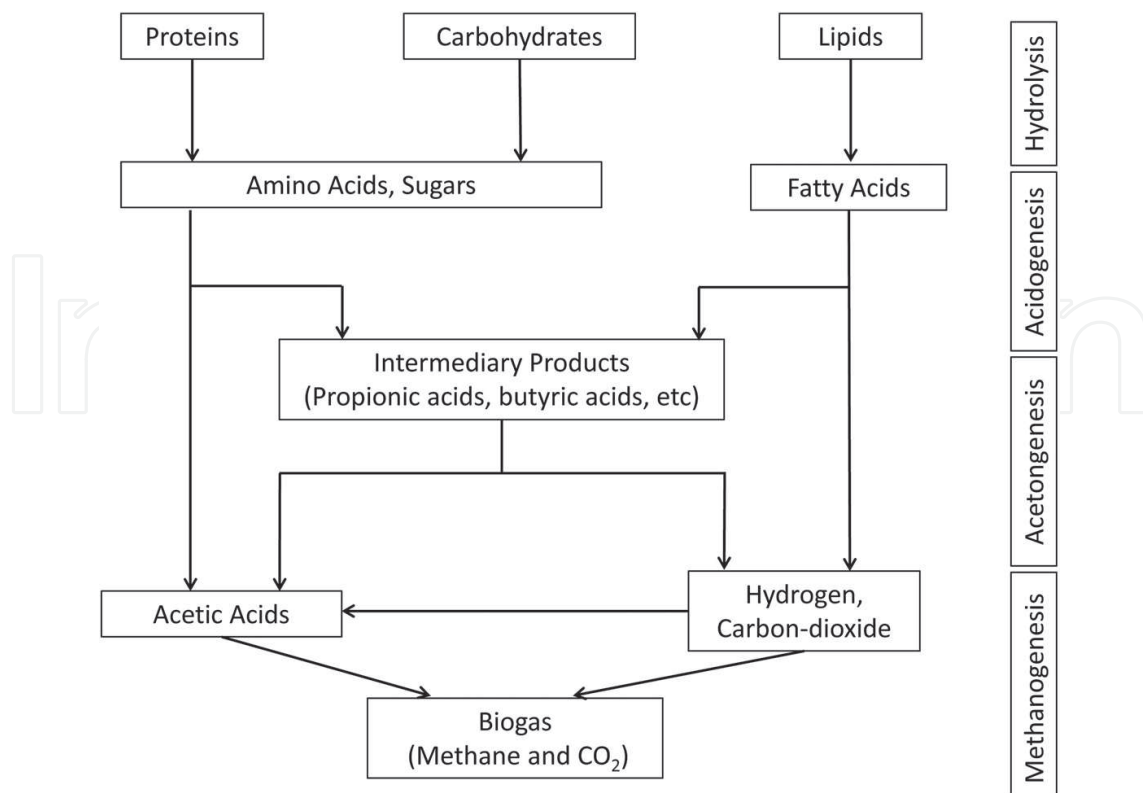


Figure 2. Stages of anaerobic digestion process. Source: modified from Ref. [6].

Parameter	Biogas from landfill	Biogas from farm-scale AD plant	Natural gas (Danish)
Lower heating value (MJ/m ³)	10.7–23.3	19.7–21.5	31–40
Methane content, CH ₄ (%)	35–65	55–70	81–89
Carbon dioxide, CO ₂ (%)	25–45	35–55	0.67–1.00
Hydrogen sulfide, H ₂ S (%)	30–500	25–30	0–2.9
Nitrogen, N ₂ (%)	<1–17	<1–2	0.28–14
Oxygen, O ₂ (%)	<1–3	<1	0
Other hydrocarbons	0	0	3.5–9.4
Halogenated compounds (mg/m ³)	0.3–225	<0.01	-
Siloxanes (mg/m ³)	<0.3–36	<0.02–<0.2	-
Theoretical combustion air (m ³ biogas/m ³)	6	6.6	9.5

Source: modified from Refs. [7–9].

Table 1. Composition of biogas and natural gas.

in an upgrading process [7]. The presence of hydrogen sulfide (H₂S) in biogas must be cleaning or upgrading to methane in order to diversify the end use of biogas in several ways.

2.2. Natural gas reserves and sources of biogas

Natural gas is a fossil fuel often found under the oceans, near oil deposits, trapped between the rock pores spaces (porous systems), and beneath the earth's surface. Similarly to the oil exploration, there are natural gas reservoirs around the planet classified as proved and undiscovered technically recoverable resources. A reservoir is a location where large volumes of methane can be trapped in the subsurface of the earth. In this respect, proved reserves of natural gas are estimated quantities that analyses of geological and engineering data have demonstrated to be economically recoverable from known reservoir in the future [10]. According to the International Energy Statistics, in 2014 there were 6973 proved reserves worldwide [10], in which the countries of Middle East and Eurasia represent the vast majority of it (**Figure 3**).

Even though natural gas has become one of the most used fuels around the world and the trends point to increase in number of proved reserves due to the application of new technologies, the world population will continue to grow and still demand more energy, so the amount of fossil fuels is not an enough resource for all the countries. As well as, the ongoing price increase of fossil resources and the visible impacts on the global warming.

Under this scenario, a versatile fuel that comes from a wide variety of biomass is biogas. It can provide a renewable source of energy and can lead to reduce impacts of pollution by inadequate waste disposal. Whereas undiscovered technically recoverable resources of natural gas are still growing, a large quantity of solid waste is also generating. Most of the countries

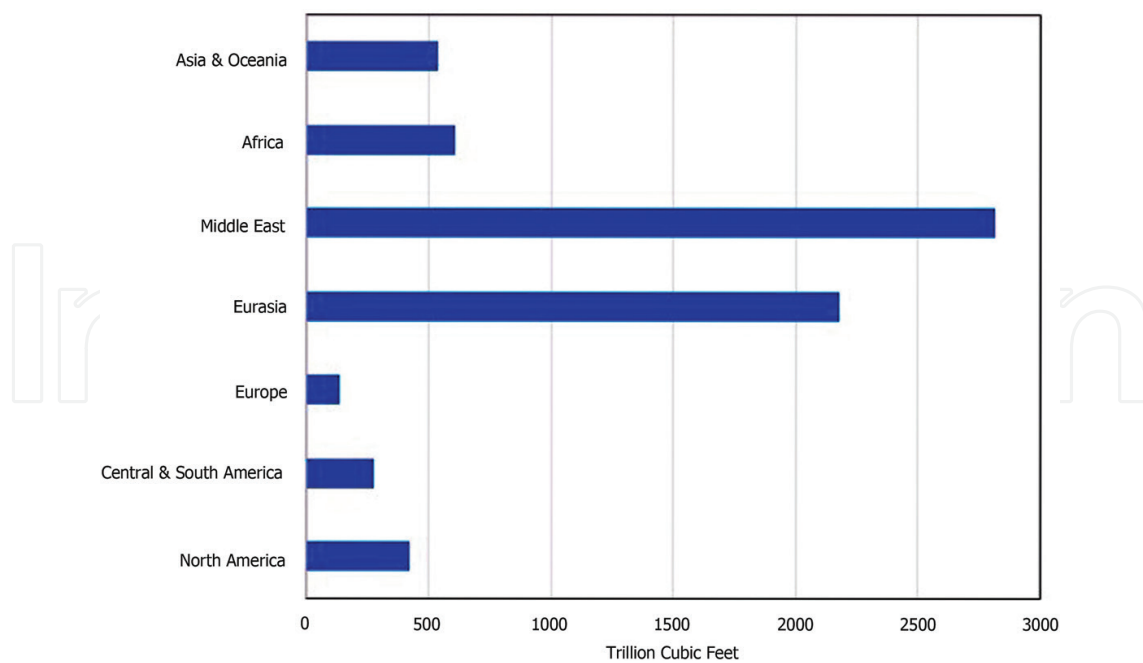


Figure 3. Proved reserves of natural gas worldwide in 2014 (with data from Ref. [10]).

around the world deal with their residues; they represent a social-environmental problem due to the lack of management. This biomass can be a harnessing nature’s potential to produce energy. It is continuously produced, free in many countries and widely available.

In this respect, the future role for biogas in the world is related with the availability of different types or organic feedstock which depends on a number of economic, social, technological, environmental, and regulatory factors. Examples of various biomass feedstocks for biogas production by sector are shown in **Table 2**.

It is predicted that by 2020, renewables will represent the 14% from the total EU energy mix, in which biomass accounts with the 54% of the 251 million tons of oil equivalents (Mtoe) (**Figure 4**). Unfortunately, most of this biomass is used in a direct way as wood, so biogas potential studies can be evaluated considering certain type of biomass.

For 2010, primary production of biogas in Europe was 10.9 Mtoe, in which 27% of the biogas was produced from landfill, 10% from sewage sludge, and 63% from decentralized agricultural plants, municipal solid waste, methanization plants, co-digestion, and multiproduct plants [13]. This biogas production increases to 31% compared to 2009. Germany is one of the countries that have doubled biogas production in the last years, and it is also one of the main biogas-producing countries for the 2020 in the EU (**Figure 5**). The acceptance and the rapidly growth of the technology show how biogas can make an important contribution to the energy supply in a short term.

Similarly to biomass demand, the biogas demand has a number of end user sectors, which have different characteristics in terms of application, economic value added, customers, social benefits, and environmental impact [14]. If biogas is conditioned or cleaned, it will be an

Sector	Type of biomass feedstock	Example of biomass	Biogas yield (m ³ CH ₄ /tonnes VS)
Agricultural	Animal manures and slurries, crops, grass, and other by-products	Pig slurry	300
		Cattle slurry	200
		Maize (whole crop)	205–450
Industrial	Organic wastes, by-products and residues from agro-industries, fodder brewery industries, organic load wastewaters, and sludge	Whey	330
		Flotation sludge	540
Municipal	Household waste, landfill, sewage sludge, municipal solid waste, and food residues	Fruit waste	300–550
		Waste water sludge	400

Source: modified from Ref. [11].

Table 2. Sources and type of biomass by sector.

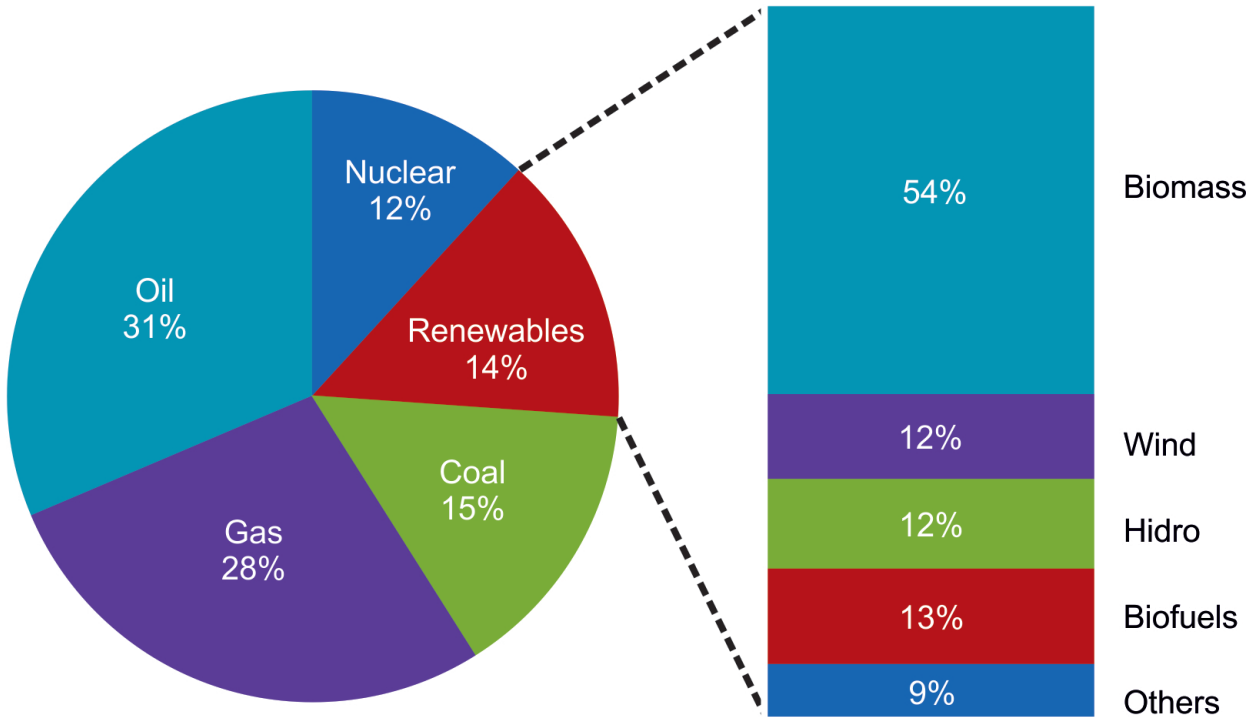


Figure 4. EU energy mix 2020 [12].

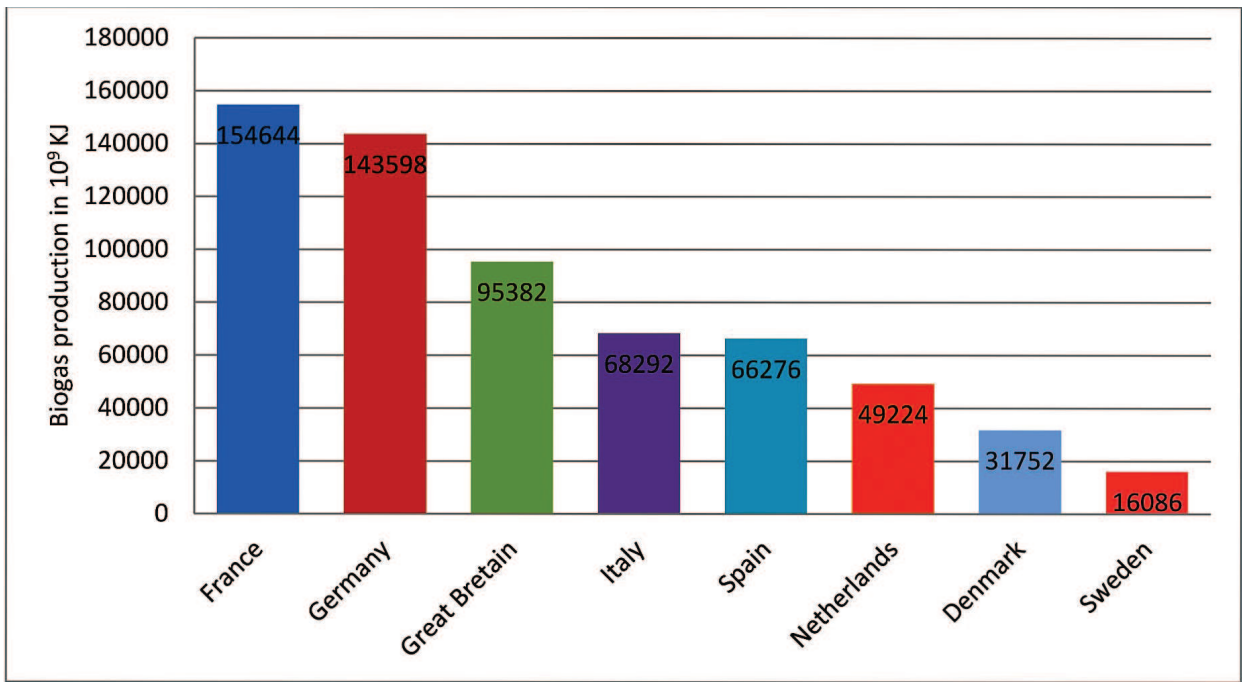


Figure 5. Biogas potential for 2020 in the EU.

outstanding solution for a variety of applications commonly known for natural gas with the addition of the versatility of its end uses. Some examples include: motor fuel, electricity, heat, combined electricity and heat, and recently replace carbon compound into plastic products [11] and also the generation of by-products that can be used as an organic fertilizer.

2.3. Advantages of biomass energy

There is an important environmental advantage of biomass utilization in terms of reduction of natural resource depletion [15], carbon neutral resource in its life cycle (Asian Biomass Handbook), and sustainable energy systems [16]. It has been estimated that by the year 2020, 50% of the present gas consumption in the Europe Union could be covered by biomethane from digested feedstock [17] contributing to the greenhouse gas capture, like methane. Also the fermentation process is an alternative for wet-bases raw residues treatment, and particularly anaerobic digestion because of the cost-effective [18, 19]. Biogas can be burned directly in boiler for heat or/and engine for cogeneration, while upgrade biogas can be injected in the natural gas grid and used directly at the consumer in boilers and small combined heat and power (CHP) [20].

3. Biomass conversion technologies

Since the last century (1897), some Asian countries, like China and India, started their first trials in using biogas [21], through a stabilization process that allows the use in household and farm-scale applications. Similarly, England reported using it in the 1930s for lighting streets

[11]. In both cases, the main biomass source to produce biogas was taken from sewage in order provide a fuel for cooking and lighting. In a brief context, the use of biomass to provide energy has been fundamental to the development of societies.

Nowadays, the demand on energy and the impact on climate change have led to calls for an increase in the use of biogas in different ways. In this section, the main process or conversion technologies employed for the biomass are presented with specific regard to biogas production.

3.1. Biomass conversion process

The biomass conversion technologies are closely related to the type of biomass, quantity, the availability, the cost-effective, and the end user requirement of the biofuel. The selection of the technology depends on the main interest of the “producer.” For all the cases, the main biomass treatments that can be applied are encompassed in four conversion technologies: direct combustion, thermochemical, biochemical and biotechnology, and nanotechnology (**Figure 6**).

It is important to note that a pretreatment of the biomass is necessary before applying a conversion technology. In some cases, biomass has to be harvested, collected, transported, or stored [22]. Further, resource availability varies from region to region, according to weather conditions, soil type, geography, population density, and productive activities, which makes the choice of technology for processing more complex.

3.2. Direct combustion

One of the oldest uses in which biomass has been utilized for energy in the world is through the burning wood (combustion). This action represents a traditional use of biomass, particularly in rural zones. It is considered an essential resource to the economic development of societies [23]. Nevertheless, when the wood is burnt in an open fire stove, around 80% energy is lost [24]. Recently, technologies suggest the use of energy efficiency stoves, which not only has a better thermal efficiency but also avoids indoor air pollutions. Other specialized equipment involves furnaces, boilers, steam turbines, and turbogenerator. The combustion of biomass allows the recovery of the chemical energy stored. In general, combustion processes

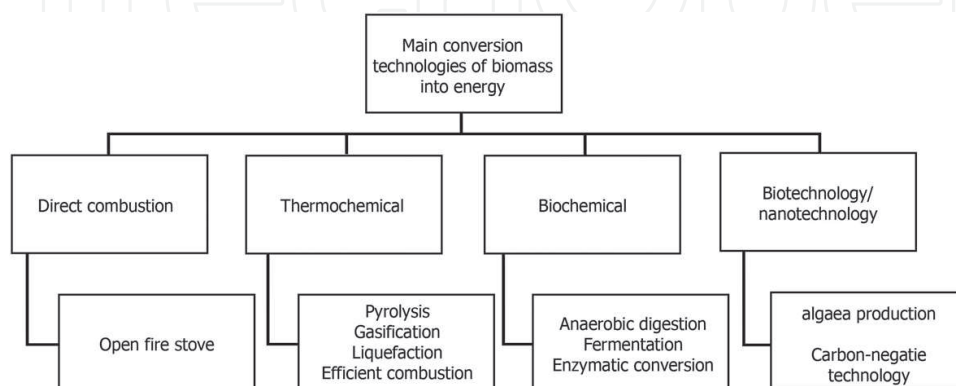


Figure 6. Conversion technologies of biomass into energy. Source: modified from Ref. [2].

involve direct oxidation of matter in air, that is, ignition or burning of organic matter in an air atmosphere sufficient to react with oxygen fuel.

3.3. Thermochemical process

Thermochemical process, as the direct combustion, has a core axis, the temperature. One of the main differences is an induced atmosphere in which conversion of biomass took place. This oxidation process can occur in the presence or absence of a gasifying medium. The conversion of biomass depends on temperature and pressure variables. For example, if the substrate to transform is in the presence of a gas such as oxygen, water vapor, or hydrogen, producing fuel is performed through gasification. If, however, material degradation occurs in the absence of oxygen, that is, nitrogen, under controlled pressure and temperature, then the process is called pyrolysis.

There are some good experiences in the pyrolysis of certain materials, in which a charcoal, bio-oil, and a fuel gas can be recovered [25].

3.4. Biochemical process

Biochemical treatment unlike thermochemical process achieves power generation through biological transformation of organic compounds, employing anaerobic digestion, or fermentation of biomass. Fermentation is usually used to produce biofuels, as ethanol, from sugar crops, and starch crops [22]. Nevertheless, there is another route, in which biomass conversion is done, the anaerobic digestion.

Among the general background information about conversion technologies, anaerobic digestion is the main focus in this section due to the direct biogas production. The anaerobic process is analog to ruminant digestion process. The biomass is degraded by a consortium of bacteria within an anaerobic environment, producing a principal product, gas. This gas, called biogas, represents a proven technology and its use is widely spreading through Europe.

For biogas production, there are some types of biomass that are more accurate, like the ones with high moisture content in organic wastes (80–90%) or wet biomass residues as manures, municipal organic solid waste, and sewage sludge [22]. The anaerobic digestion process generally occurs in reactors or tanks in a single, multistage process or dry digestion.

Anaerobic digester can be categorized, designed, and operated by different configurations: batch or continuous, temperature (mesophilic or thermophilic), solid content (high or low solid content), and complexity (single stage or multistage) [26]. Another specific configuration considering the organic rate load, digester, is divided into passive systems (covered lagoons), low rate systems (complete mix reactor, plug flow, and mixed plug flow), and high rate systems (contact stabilization, fixed film, suspended media, and sequencing batch) [27]. All these types of reactors perform the anaerobic digestion, but each one operates for salient features with a variety of applications of the end products.

An experience in the livestock sector in Mexico using covered lagoon anaerobic digestion reactor shows benefits in the use of biogas not only on environmental aspects as improving

the quality of wastewater but also economically due to the avoid of penalties for the water discharges and the social acceptance of the livestock activity in the region (**Table 3**).

Biomass residue (swine manure)	Technical aspects
Number of animals (head of animals)	32,483
Manure produced annually (tonnes/y)	115,315
Biogas production (m ³ /y)	2,538,389
Energy consumption (kWh/y)	52,072
Energy production (kWh/y)	255,528
Emission reductions (tonnes CO ₂ e)	14,027

Source: using data from Ref. [28].

Table 3. Biogas production experience in livestock sector in Mexico.

In this example, the different benefits of biogas production in livestock sector highlighted the use of biogas in energy generation. Against other energy sources, in this case, the biogas produced is used in the farm for their own consumption by a gas combustion engine. The heat generated by the motors can be used for heating the reactor or drying waste. Biogas has the quality that does not have to be consumed at the moment of production. The production of this biofuel also impacts in macro- and microeconomic aspects, due to the generation of new sources of employs and access to energy in a remote place. Moreover, the livestock producer is selling an organic fertilizer obtained by high-quality digestate obtained in the biogas production.

Furthermore, odor reduction and the removal of pathogenic organism in livestock residues are achieved. The methane emission of the manures is captured, reducing the release of methane to the atmosphere. Methane (CH₄) is considered one of the largest contributors to the GHG emissions by livestock sector, with a global warming potential 25 times more than carbon dioxide (CO₂) [29, 30].

In general, the biomass conversion technologies mentioned above can be integrated into the concept of biorefinery. Analog to oil process, the different biomass feedstocks offer a wide range of products that can be used as fuel, including gas, oil, or chemical, offering greater possibility of using cogeneration systems and supply facilities in the transport sector.

4. Biomethanization process

When the major end product in a biogas plant is methane, similar to natural gas, this upgraded gas is called biomethane. The methane content determines the energetic value in the biogas [11]. In this respect, one of the main reasons for upgrading biogas to a degree equivalent to natural gas is to inject to the gas distribution network and thus diversify some natural gas sources.

Biomethanization process opens new paths to achieve this goal: first, because the gas storage in an extended way allows the injection into a distribution system and second due to the variety use of fuel in transport stations, mainly.

As we see in the sections above, the main biogas uses in development countries are lighting, cooking, and further in gas turbines. In industrial countries biogas is produced in large-scale digester (biogas plants) with an interest in the concentration of methane from biogas to fulfill natural gas standards. Depending on the end use, different biogas treatments (cleaning or upgrading) are necessary. For example, vehicle gas fuel requires a biogas similar to natural gas quality so a biogas upgrading process is needed. In other words, biomethanization allows biogas to be contained, controlled, and distributable.

4.1. Biogas cleaning

There are some undesirable components in biogas that promote corrosion in many materials and engines: H_2S , oxygen, nitrogen, water, siloxanes, and particle traces (see **Table 1**). These impurities can induce or promote corrosion in many parts of the biogas system or equipment in which biogas is used. Overall, these components must be removed in order to allow the concentration of methane in biogas.

Water content in biogas can cause corrosion in pipelines due to the formation of carbonic acid in a reaction derived from water and carbon dioxide [31]. Fortunately, it can be removed by cooling, compression, absorption, or adsorption (activated carbon, sieves, or SiO_2). Hydrogen sulfide (H_2S), another unwanted component in biogas, is of corrosive nature, leading the damage of motor engine, pipes, etc. It is a highly toxic gas that attempts to destroy the human health. The removal of hydrogen sulfide can be done by precipitation, adsorption on active carbon for H_2S removal (US 8669095 B2 patent) [32]. Siloxanes also constitute an impurity in biogas. It can affect combustion equipment, as gas engine, through the formation of silicon oxide. The most common methods for removing siloxane components are adsorption on activated carbon, activated aluminum, or silica gel, mainly [31].

After desulfurization and drying process of biogas, it can generate electricity and heat in cogeneration systems, combined heat and power (CHP), or can be transformed to energy products with higher value, density, and calorific value.

4.2. Biogas upgrading

Around the world, the number of upgrading biogas plants has increased, reaching 100 during 2009 [7]. This facility has gained the world's attention due to the rising oil and natural gas prices.

The biogas obtained during anaerobic digestion of biomass contains important amounts of carbon dioxide that result in lower energy content. In order to improve this characteristic, the separation of carbon dioxide through an upgrading process is requested. Cleaning the gas before upgrading is recommended.

Compared with the common uses of biogas, the upgrading of biogas brings several advantages related to transportation of the gas and offering the chance to increase the overall efficiency of

gas utilization. In this part, it is important to clear up that cleaning biogas refers to the separation of impurities, while upgrading refers to the separation of CO₂.

Currently, there are several technologies for biogas cleaning and upgrading, commercially available, like pressure swing adsorption (PSA) (US 6340382 B1 patent) [33], water scrubbing, organic physical scrubbing, and chemical scrubbing. Most of them are a combination or one or two processes for biogas cleaning or upgrading (**Figure 7**).

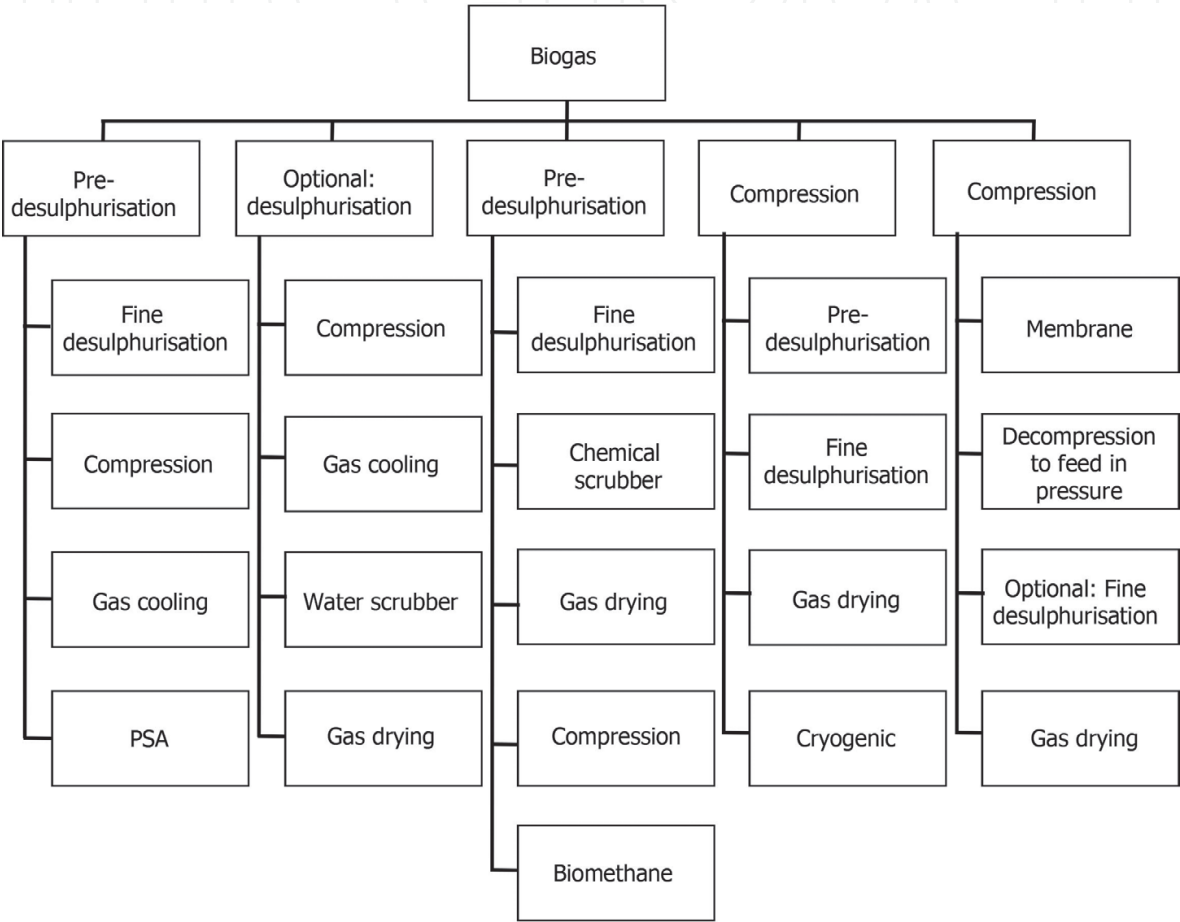


Figure 7. Different biogas cleaning and upgrading of biogas. Source: adapted from Ref. 34.

If biogas is upgraded to biomethane with approximately 98% of methane content in biogas, it can have the same properties as natural gas [35]. By these standards, biomethane can be fed into the available gas network or be used for any purpose for which natural gas is used. The overall environmental benefits of the use of biogas are, however, highest when the biogas is used as a vehicle fuel replacing oil or diesel [4].

In fact, the selection of the optimal technology for biogas upgrading depends on the quality and quantity of the raw biogas to be upgraded, the desired biomethane quality and the final use of the biogas, the anaerobic digestion system, the continuity of the biomass, as well as the local circumstances [36].

5. Opportunities for bio-based economy (green natural gas)

The current leader in the deployment of biogas technology is Germany. In the last decade, the number of digester plant increased ten times compared to 1996 (Poeschl et al., 2010). The German scheme is a clear example for biogas technology promotion; it highlights the employment of key instruments for helping to spread out the technology, that is, economic incentives.

Broadly, biogas production in different countries is still dependent on subsidies for attracting investors, producers, and I&D groups and promoting its scalability. Certification systems, feed-in tariffs, and investment support are examples of measures that are widely applied (Table 4). Some of the policy documents and directives that are related to bioenergy are included in three EU regulatory frameworks: the Renewable Energy Directive (2009/28/EC), the Directive on Waste Recycling and Recovery (2008/98/EC), and the Directive on Landfill (1999/31/EC) [37].

Country	Incentive	Scope of support
Germany	Feed-in tariff	Electricity and heat from biogas. Tariff according to system size and fuel
	Market premium	Biogas and biomethane
	Gas processing bonus	Upgraded biogas for grid injection and transport
	Flexibility premium	Electricity from biogas
The UK	Feed-in tariff	Electricity from biogas
	Renewable obligation order	% RES from electricity production (>5 MW)
	Climate change levy	Favors any type of renewable energy generation
	Renewable heat incentive	Biomethane injection and biogas combustion, except from landfill gas
Sweden	Certification system	Certificates for electricity from biogas
	Energy taxation	Tax benefits for electricity, heat, and transport from biogas
	Investment support	Farm-based biogas production

Source: modified from Ref. [37].

Table 4. Examples of incentives schemes for biogas production.

6. Conclusion

Most of the countries around the world are still dependent on energy supplies, mainly by fossil fuels. Societies need to secure the energy demand, through social equality and mitigating the environmental impact. In this respect, biogas production is not only a promising way but is currently one of the most renewable technologies capable of offer energy, as such fossil fuel does.

Biogas can play the pivot role in the renewable sustainable energy systems in the near future due to its versatility, availability, storability, and energetic value. In this context, adequate public policy (regulation) for promoting economic, social, and cultural conditions for biogas production is still necessary.

Even though the technology has been adopted by many countries in Europe, there is still a necessity for developing and applying more adequate technology for cleaning and upgrading biogas to biomethane in places in which the use is limited (grid injection), which is becoming a present challenge.

Biogas and biomethane benefits promoting is required to overcome the reliability of the anaerobic process and the use of the by-products, increase the ability of the enterprises to satisfy the market necessities, and involve the government, public, private, and actor in this important task for reaching to a sustainable energy system.

Acknowledgments

The support and valuable comments from a Master of Science (Latin: Magister Scientiae). Oscar Silván-Hernández and Dr Alejandro Ordáz-Flores are greatly appreciated.

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