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226. Future prospects of biogas in Pakistan

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Abstract

Biogas is an eco-friendly technology. The organic wastes for biogas production consist of animal excrements, rawwood for fuel, agricultural waste (AW), organic fraction of municipal solid waste (MSW) and food waste (FW) and Pakistan, being an agricultural country has excess availability of these resources. Anaerobic digestion of these organic waste has great potential of biogas production, its composition mainly consist of methane (CH_4) and carbon dioxide (CO_2). A single cow or buffalo may produce averagely fifteen-kilogram dung in a day. Almost 6 kg of dung can produce 1m3biogas, so from this calculation a single cow or buffalo can produce almost 2.5m^3 biogas in one day normally. Almost 2.5 KWh electrical power can be generated from 1m^3 of biogas. The livestock sector of Pakistan is growing annually at the rate of 4% and approximately 35.625 million KWh electrical power can be generated from its dung per day. A considerable biogas can be produced from 785 million available poultry birds in Pakistan and this gas can be used to generate electricity and heat. The main agricultural crops of Pakistan are cotton, sugarcane, maize, rice, wheat etc. and their residues have great potential for biogas production to produce electrical energy. Pakistan is world's fifth major sugarcane producer country and it produces sugarcane approximately 50 million tons annually and produces 10 million tons bagasse. There are about 80 sugar mills having potential to generate almost 3000 MW energy through biogas generation. One gram of cotton waste like cotton oil cake, cotton seed hull, cotton stalks has ability to produce approximately 78, 86 and 65 ml methane (CH_4)respectively along with basal medium (BM). Co-digestion is a good technique to enhance the biogas production. Co-digestion of food waste (75%) and animal manure (25%) can produce biogas of 14,653.5 ml/g-VS. Similarly, municipal solid waste can produce 200-530 liters/ kg biogas. Pakistan Council of Renewable Energy Technologies (PCRET) has saved 37.925 million rupees monthly by installing 4109 biogas plants throughout the country in terms of LPG (liquefied petroleum gas), kerosene oil, bio fertilizer and wood. The estimated potential of biogas is 12–16 million m^3/day. Therefore, according to the current circumstances, government of Pakistan should launch a wide-ranging program for commercialization, R&D and knowledge to the public to adopt renewable energy technologies like biogas for the sustainable energy supply of the country in future.

Keywords: *Animal dung; agricultural waste; food waste; municipal solid waste; anaerobic digestion*

1. Introduction

Biogas (CH_4) is a gas, which is produced from the digester by the action of a group of anaerobic bacteria such as hydrolytic, methogen, acetogens and acidogens, which decompose organic waste. Biotechnology of biogas generation usually refers to the anaerobic digestion of different types of organic wastes like food waste (FW), sewage sludge; waste of food industry, animal excrements, organic fraction of municipal wastes (MSW), and agricultural waste for biogas production usually refers to biotechnology. In some countries, plants like maize are grown for anaerobic digestion [1, 2].The biogas composition depends on the nature of organic waste, which is subjected to the anaerobic digestion procedure and the conducting method for the procedure and is as follows: Methane CH_4 (50–75%), carbon dioxide CO_2 (25–45%), carbon monoxide CO (0–2%), hydrogen sulfide H_2S (0-1%), nitrogen N2 (0–2%), hydrogen H_2 (0-1%), ammonia NH_3 (0-1%), oxygen O_2 (0–2%), and water H_2O (2–7%)[3]. Digestion associated with biogas generation may have three positive roles. First, it is a biochemical technique to convert the biomass energy into a practical bio-fuel such as biogas, which can be easily stored and transported from one place to another place. Next, it is a recycling method to convert organic wastes into a valuable liquor fertilizer as a stable soil additive, and energy. Finally, it offers a good method for the treatment of organic waste in order to reduce its potential hazardous effects on our environment [4].

From the previous ten years, Pakistan has been facing very serious energy crises. Pakistan's government spends a large amount of 14.5 billion US dollars every year to meet their energy needs in order to import fossil fuel. The non-renewable energy use and exploration is not enough to meet rapidly increasing demand of energy for the increasing population. The load shedding is recorded for 14–20 hours in a day in Pakistan, resulting in practically completely suspended social life [5]. The circumstances have forced Pakistan's Government to take some bold decisions such as market shutdowns at early, two holidays in one week and disconnect the power to industry, consequently affecting almost all the business activities; in addition, we put all efforts on oil based power project like rental power project to meet our power needs. At this time, for both government and consumers it is almost impossible to tolerate the price of electrical energy due to the existing oil-based projects. The country needs to have an out-of-the-box opinion to utilize its native resources, like coal, hydro and renewable energies [6].

Pakistan, being an agricultural country, annually produces million tons of solid organic waste in the form of biomass such as corn cobs, cotton waste, rice husk, wheat straw, wheat stalk and other energy crop residues; this biomass has great potential for biogas production [6]. A single cow or buffalo may produce averagely fifteen-kilogram dung in a day. Almost 6 kg of dung can produce 1m^{3}biogas, so from this calculation a single cow or buffalo can produce almost 2.5m^3 biogas in one day normally. Almost 2.5 KWh electrical powers can be generated from 1m^3 of biogas [5]. In Pakistan, total 172.2 million livestock animals produce 652 million kg dung per day. This large amount of dung can be used for biogas production [5]. Biogas can also be produced from number of organic wastes like waste of banana stem, slaughterhouses wastage, waste of paper industry, poultry waste and street waste except animal dung [8, 9]. The present energy crisis of Pakistan can be overcome by utilizing this biogas as a renewable energy and alternative source. The total potential of biogas available in the country is 14.25 million meter cube per day [7].In the year 1959, Pakistan has installed its first biogas plant in Sindh [10]. In 1974, Pakistan Council for Appropriate Technology (PCAT) has installed 10 biogas plants installed in Azad Jammu & Kashmir. In the same year, Directorate General of New and Renewable Energy Resources planned to launch a project with the aim to set up 4000 biogas plants by 1986. Later on, Biogas Support Program (BSP) was launched to establish 1200 biogas plants in year 2000 and 10,000 biogas plants were projected to be established until 2006. Pakistan Dairy Development Company (PDDC) also took a part in biogas plant installation and 556 plants have been installed under this program by 2009[11]. There are 14,000 biogas plants with the cost of Rs. 356 million which have been installed by Rural Support Program Network (RSPN) starting from 2009 (GOP economic survey 2009-2010). Pakistan Council of Renewable Energy Technologies (PCRET) is installing various renewable technologies (RE) to overcome the present energy crisis. Since 2002, PCRET has installed 4016 biogas plants throughout the country. These biogas plants are producing 20, 545 m^3/ day biogas according to the government of Pakistan, Ministry of science and Technology, 2014. Details of biogas plants installed in the country by PCRET are given in Table 1.

Table 1: PCRET installed biogas plant in Pakistan during2002–2012[5]

Provinces	Biogas plants installed (2007 - 2012)
Islamabad	30
Punjab	1700
KPK	155
Sindh	300
Baluchistan	80
AJK	50

Biogas provides environment-friendly and renewable energy, which will keep the environment clean and green and will help to stabilize ecological unit. On commercial scale, biogas plants can be installed for generating cheap electricity to defeat electric power shortfall, In addition, getting cheap bio-fertilizer. By adopting new technologies and pre-treatment techniques, biogas plant efficiency can be improved for commercial scale. In literature, many topics deal with a variety of enhancing techniques, controlling methods and optimizing techniques of anaerobic digestion (AD) and improving biogas yield and/or biogas quality. Therefore, in Pakistan, there are wide prospects of biogas.

2. Potential of Biogas energy from various organic resources in Pakistan

Every kind of biomass can be utilized as a substrate for biogas production as long as they enclose fats, carbohydrates, hemicelluloses, proteins and cellulose, as major components. The chemical composition, quality of biogas and the yield of methane mainly depends on the quality of feedstock type, time of retention, the anaerobic digestion system [12]. Biomass is a resource that can take part in a significant function in a sustainable and more diverse energy mix. Bio-power is the use of biomass to produce electricity. Bio-power systems have six most important types: pyrolysis, direct-fired, anaerobic digestion, co-firing, modular systems and gasification [13]

As an agricultural country Pakistan is producing annually million tons of agricultural waste in the form of biomass such as maize stalks, cotton sticks, sugarcane trashes and bagasse, paddy and wheat straw, rice husk etc. with total 22.2 million ha cropped area. Available agricultural waste in Pakistan is almost 81 millions of tons every year that has the capacity of electricity generation of 45, 870 million kWh [14].

It is predicted that wheat, rice, cotton, maize, sunflower sugarcane, mustard, and canola crops in the country have biomass potential of 35.27, 9.24, 40.78, 8.5, 0.35 29.0, 0.20, and 0.13 million of tons every year, correspondingly. The Punjab has a surplus agricultural waste about 27.86 million of tons to generate 15,777 million kWh electric power per year. Pakistan has about 3000 MW of electric power generation likely in the industry of sugar while it is generating only 700 MW [15]. Thermal value of different biomass materials employing standard techniques have been shown in Table 2.

Table 2: Heating value of some agriculture waste [15]

Type of biomass	Kcal kg^{-1}	MJ kg^{-1}
Wheat straw	3800	19.4
Rice husk	3040	11.5
Sugarcane	3800	19.5
Paddy straw	3000	11.4
Cotton stalk	4700	17.8
Maize stalk	3500	13.6
Maize cob	3850	19.6
Bajra stalk	3950	18
Gram stalk	3810	19.4
Masroor straw	3980	18.1

There are several methods which can be introduced to produce energy from different feedstock (biomass) [16]. These processes can be divided into the following types as shown in Fig. 1.

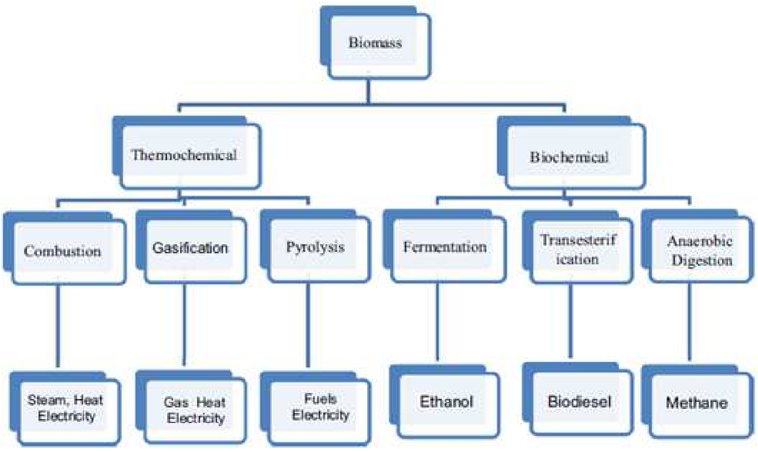

Fig 1.Energy production routes from wastes and their outputs

Biomass is a sustainable renewable energy source and is widely available. Its production use has additional social and environmental benefits. If correctly managed, biomass can result in a significant reduction in net carbon emissions when compared with fossil fuels. The energy conversion efficiency of the conventional fossil fuel technologies can be high but they are quite inefficient in carbon conversion because of high CO2 emissions[17]. At present, Pakistan does not have a single biomass/waste power plant [18].

3. Biogas technology

Various applied biogas production processes are classified into two main categories, wet fermentation processes and dry fermentation processes. In wet digestion processes, the concentration of total solids in the fermenter is kept less than 10%. These processes require completely stirred digesters. The digested material is pump able and can be spread on fields for fertilization. For the treatment of solid substrates, e.g., energy crops, the input must be mixed with liquid manure or recycled process water in order to achieve pump able slurries. Dry digestion processes are operated with total solids content inside the fermenter between 15% and 35%. All wet digestion processes are operated continuously whereas for dry fermentation, batch and continuously-operated processes are applied. Today, wet digestion processes dominate in the agricultural sector [19].

Weiland had proved that theoretical yield of gas varies with proteins, fats and carbohydrates (as given in Table 3). Only the substances with strong lignin organic like wood are not suitable for biogas production due to its slowly anaerobic breakdown. The experimental content of methane is normally higher than the hypothetical values because some part of CO_2 is dissolved in the digestate [19].

Table 3: Real gas yields and theoretical contents of methane [19]

Organic Substrate	Biogas (Nm3/t TS)	CH4 (%)	CO2 (%)
Carbohydrates	790-800	50	50
Raw protein	700	70-71	29-30
Raw fat	1,200-1,250	67-68	32-33
Lignin	0	0	0

The hazardous effects of organic waste on environment can be reduced by using anaerobic digestion method and it is a beneficial treatment method of wastes. The mutually action of different groups of anaerobic microbes results in the breakdown of complex organic matters into simple compounds such as CH_4 and CO_2 that are chemically stabilized. These different groups of microorganism such as fermentative, acetogenic, syntrophic and methanogenic bacteria are responsible to produce CH_4 and CO_2 [20].

There is a lot of Biogas potential in Pakistan. This technology can provide almost three times more useful energy than that produced by direct burning of dung. This technology can improve economic condition of the rural area population of the country. The other advantage is abating the emissions of GHG that would pollute the environment due to its direct exposure. This technology is environment friendly because it reduces emissions and develops healthy environment.

4. Sources of Biogas

There are a number of sources of biogas production, so we discuss them in detail:

4.1 Biogas Production by animal dung

Animal manure consists of moisture, organic material and ash. The decomposition of animal manure can be carried out in both aerobically and an an aerobically ways. In aerobically condition, it produces carbon dioxide (CO_2) and chemically stabilized organic materials. However, in anaerobic way, stabilized organic materials, methane (CH_4) and carbon dioxide (CO_2) gas are produced. In Pakistan, cows, poultry farms, buffaloes, camels, goats, sheep and horses are the general sources of animal manure. Common use of animal manure in Pakistan is as a rich fertilizer to enhance the fertility of the land. However, the biogas generation under anaerobic conditions can help the people in rural area of the country. Additionally, slaughter house waste can be also used for the biogas production in order to generate electricity, on a small scale. The amount of manure from an animal in a day depends on its breed, age and feeding habits. This also implies that the amount of manure yielded changes with the temperature [16].

It is estimated that the number of livestock and poultry are increasing day by day with a growth rate of 2.88% in 2013–2014.Therefore, the extent of manure is also being produced positively [21]. Table 4 shows Potency of livestock in Pakistan [41].

Table 4: Annual livestock yield in Pakistan

Types of livestock	No. of livestock in millions
Cattle	41.2
Buffalo	35.6
Sheep	29.4
Goat	68.4
Camels	1.0
Horses	0.4
Asses	5.0
Mules	0.2

There are 51 million animals (buffaloes, cows, bullocks) in Pakistan. Anaerobic fermentation of this animal's dung can produce enough biogas to meet the cooking requirement of 50 million people. More than 100 million people out of total population of 170 million live in rural areas of Pakistan. Therefore, we can meet the cooking/heating needs of about 44% rural population from this single source of energy. Besides biogas, this technology produces 57.4 million kg nitrogen enriched bio-fertilizer daily, which is very essential thing for fertility of agriculture land [18].

Animal manure is considered as primary digestion substrate for biogas production. Rate of biogas production can be enhanced by co-digestion of animal manure and other organic materials like food waste [42].Animal manure or dung is an inexpensive feed stock and easily available in abundant quantity for anaerobic digestion to produce biogas, in any agricultural country like Pakistan. Poultry waste is also the best feed stock for biogas production [43].Graph shows the production of manure by different livestock.

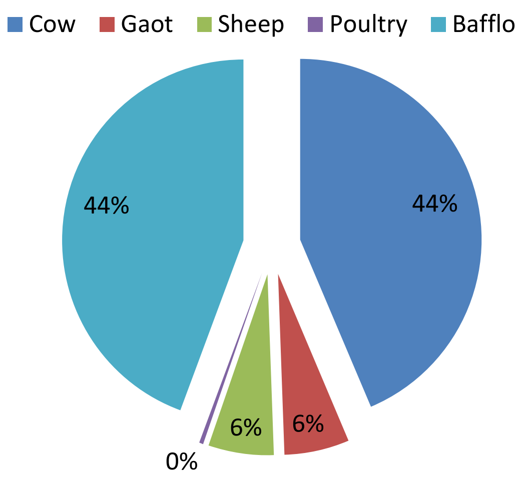

Fig.2. Production of manure per year by different Animals in kilograms [44]

A cow/ buffalo can produce 15 kg average dung per day. 1m3 can be produced from 6 kg of dung, so single cow / buffalo can produce an average of 2.5m 3 biogas in a day [5]. An already mentioned assumption is that 2.5 KWh energy is generated from 1 cubic meter of biogas. Using that assumption 51.3625 MWh/day energy can be generated from biogas in Pakistan with the help of currently installed plant by PCRET, while 35.625 million kWh/ day energy can be generated by utilizing the total potential of dung. In the Punjab, 4 MW electric powers is being generated from biogas [5].

4.2 Biogas Generation by Agriculture Waste

Biogas production in the agriculture sector is a very fast growing market in Europe and finds increased interest in many parts of the world. In the next few decades, it will be the most significant renewable energy source, because it offers an economical attractive alternative to fossil fuels. The success of biogas production will come from the availability at low costs and the broad variety of usable forms of biogas for the production of heat, steam, electricity, and hydrogen and for the utilization as a vehicle fuel. Many sources, such as crops, grasses, leaves, manure, fruit, and vegetable wastes or algae can be used, and the process can be applied in small and large scales. This allows the production of biogas at any place in the world [19]. The farmers' profit in this case is double since they treat properly their own residues, taking

advantage of the selling of heat and electricity as well as the utilization of a stabilized bio-fertilizer [22]. A large amount of agricultural wastes is being produced in Pakistan every year and this waste has great potential to produce high-value by-products. It is disposed in different ways like fuel for brick kiln and for cocking but anaerobic digestion is the best solution for agricultural waste generating efficient energy and preventing pollution. It is essential to inform the farmers about the suitable conditions to adopt according to local situations treating their own agriculture residues.
Pakistan is world's 5th largest sugarcane producer with an average annual production of 50 million tons cane and 10 million tons of bagasse. According to an estimate there are about 80 sugar mills having potential to generate almost 3000 MW energy through biogas generation but they are currently operating at 700MW [23]. The crops produce most of the residues that can be used to generate energy for example cotton produces cotton stalks; rice produces rice husk. Rice husk, rice straw and bagasse from sugarcane cover 46% of the total biomass energy potential [16]. The anaerobic treatability and methane generation potential of three different cotton wastes namely, cotton stalks, cotton seed hull and cotton oil cake were determined in batch reactors. In addition, the effects of nutrient and trace metal supplementation were also investigated. The results revealed that cotton wastes can be treated an-aerobically and are a good source of biogas. Approximately 65, 86 and 78 ml CH4 were produced in 23 days from 1 g of cotton stalks, cotton seed hull and cotton oil cake in the presence of basal medium (BM), respectively. BM supplementation had an important positive effect on the production of biogas [24].

4.3 Biogas by food waste

A roughly estimate shows that, about 40 percent of prepared food at different formal meal is wasted and thrown out at open places which can create many environmental problems. In wedding feast, people rush towards foodstuff and fill their plates and dishes with all types of food more than they can eat. Both guests and hosts are equally responsible for the food wastage at a formal meal and wedding feasts. Additionally there is a traditional practice in the Indian subcontinent that a rich host feeds his respected guests with healthy food. The UN Food and Agriculture Organization (FAO), has estimated that food wastage in developing countries is approximately 40 percent. All over the world, about 1.3 billon of tones food is wasted annually. In marriage halls, approximately hundreds of functions in the city area are held and on the host's direction, delicious and delightful foods are prepared for the guests but they do not think about food wastage while eating and they waste food over 50 percent [25].

Amount of FW is increasing by increasing population and urbanization yearly [26]. Disposal techniques of this FW create serious problems and challenges for both food safety and environmental considerations because of the high moisture content in food and concerns [27]. FW from hotels, restaurants, houses and wedding halls can be used for biogas production due to its calorific value, high biodegradability and nutritive value to microbes [28].

The FW contains high moisture content (> 70%), Volatile Solids (> 95%) and high ferment ability [29]. Food waste mainly consists of organic materials such as proteins, carbohydrates, cellulose and lipids and also has varying amounts of suspended solids depending on the source and high biochemical oxygen demand (BOD) or chemical oxygen demand (COD). The system having excess amount of lipids gives the highest yields of CH_4but retention time is very long. Generally, the food waste has lesser content of static contaminants such as sand, stones etc. On the other hand, food waste may lead to increase some other impurities like plastics and output may have high salt content. The methanization process boosts up with excess amount of proteins subsequently the reactors containing excess amount of cellulose and carbohydrates respectively. However, the excess amount of lipids and proteins impose inhibitory effects due to the volatile fatty acids (VFA) accumulation and ammonium nitrogen respectively [30].

Co-digestion of animal manure 25% with 75%of food waste can produce biogas of 14,653.5 ml/g-VS [31]. FW also contains some such organic soluble in very high amount that can be simply converted to VFAs. VFAs may cause severe drop in pH during digestion at early stage and slow down the methogenesis process [32]. In order to decrease the inhibition effect of organic acid produced, during anaerobic digestion of FW at initial stage, co-digestion technique of carbohydrate-rich feedstock with other organic or with two-phase co-digestion method is an effective way as already has been proven by Lu et al [33].

4.4 Biogas Production from Municipal solid waste (MSW)

Municipal solid waste (MSW) consists of the mixture of inorganic wastes, fresh, safe and harmful, quickly and slowly generated from different sources in metropolitan areas due to human being activities. The generation of MSW depends on seasons and the socio-economic behavior of households members. The amount of MSW in any city increases with increase in population, living standard and with the industrialization. The massive amount of MSW production is a severe environmental for the developing countries. Pakistanis facing very severe environmental problems too due to the rapid and uncontrolled generation of large amount of MSW and its mishandling [34]. In Pakistan, households, hospitals, commercial sites and industries are the main sources of MSW. To fix this MSW problem, Pakistan's government has signed a contract with the Turkish Government to collect and manage solid wastes [16]. Table 5 describes the potential of MSW in the biggest metropolitan cities of Pakistan. The maximum power potential is available in big metropolitan city Karachi followed by Lahore, Islamabad, and Multan due to collection efficiency, the living standard and the living habits. The total estimated power potential in only10 main cities of the country is approximately equal to 242 million of cubic-meters.

Table5Municipal solid waste (MSW) production in the main metropolitan cities of Pakistan [35, 36, 37, 38].

Cities	Population (Millions)	Wastes collected (ton)	Organic waste (tonn)	Energy (million m^3)
Islamabad	0.74	225	216	22
Rawalpindi	1.77	320	144	14
Lahore	6.29	953	639	64
Karachi	11.62	1378	716	72
Peshawar	1.24	149	67	7
Quetta	0.73	100	37	4
Faisalabad	2.5	296	136	14
Multan	1.45	325	211	21
Gujranwala	1.44	128	51	5
Hyderabad	1.39	374	206	21
Total	29.18	4248	2423	242

5. Uses of Biogas

The both upgraded and raw forms of biogas can be used through different pathways. Commercially biogas can be utilized in:

i. The generation of electricity with combined heating power (CHP) system or fuel cells,
ii. In industry it is used as multi-generation of steam, heat, cooling and electricity,
iii. As inoculation in the gas grids,
iv. Fuel for transportation
v. For chemicals production.
vi. For cooking and lightning in rural areas,
vii. To stabilize occasionally operated solar and wind systems of renewable energy [17] or (8) energy storage applications.

In addition, other useful products of biogas include digestate used as organic fertilizers, organic fertilizer resulting poorly digestible biomass and bio hydrogen. Organic fertilizers and digestate are very useful in the systems of sustainable cropping whereas bio hydrogen is very useful in bio-refineries [39].

The major energy Input to Output (PEIO) of small and large scale biogas methods of utilization ranges between about 4–46% and 1–34%, respectively, depending on the applied energy conversion systems and fossil fuel replacement. This wide range practicable by state-of-the-art technologies proposes the system that is based on biogas structure and the participation of procedure innovations play a major role in ensuring energy efficiency improvement and finally economic feasibility of biogas utilization systems [40].

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