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A Case Study on: Annual Availability of Feedstock and its Impact on Biogas Production Cost

Jasleen Bhatti[1] and G.N. Tiwari[2]

[1,2]Centre for Energy Studies, Indian Institute of Technology, Hauz Khas, New Delhi 11 00 16, India
E-mail [1]bhattijasleen@gmail.com, [2]gntiwari@ces.iitd.ac.in

Abstract—*Biomass is organic matter rich in carbon content obtained from plant or animal origin. It serves as an excellent source of feedstock for biogas production. The biodegradability of the organic substrate is one of the most critical parameters that affect the quantity and the quality of biogas produced. The convertibility of some common substrates into methane varies in between 30% to 50%. The potential yield of methane can be increased by upto 2 to 3 times if the substrate is rendered 100% degradable. This can be achieved by carrying out any one of these pretreatments - physical and chemical, physical, and biological. In case of physical and chemical pretreatment the equipment administered are expensive and the chemicals used are costly thus this method is not appropriate for developing countries. In the second method feedstock is made to undergo physical pretreatment which involves cutting, grinding, or shredding. This results in an increase in the surface area per unit volume and as a result the exposed area for attack by mesophilic bacteria is substantially increased. The third method is biological method, it involves pre-composting of agricultural residues before digestion. The second and third methods are applicable for developing countries. In this communication, we have concluded that the cost of biogas production can be reduced considerably by using locally available feedstocks which would ensure minimal cost of transportation and also in-expensive pre-treatment methods should be used. Finally, availability of feedstock throughout the year would ensure that the biogas plant remains functional without fail.*

Keywords: *anaerobic digestion, biomass, biogas, feedstock*

1. INTRODUCTION

Plants contain organic carbon based materials which are termed as biomass. This biomass is transformed into biofuels by either chemical, physical or biological processes. In chemical form biomass is stored solar energy and can be easily converted into solid, liquid and gaseous energy carriers . Since biofuels are non-polluting and they also render natural ecological cycles sustainable. Hence, we can say that bioenergy from biofuels is an excellent source of renewable energy which is also the need of the hour. In the 21st century one of the most crucial issues is the prevention of an energy crisis. It is a known fact that the demand for energy is increasing at an alarming rate which is eventually proportional to the economic growth of a country. Based on this, the International Energy Agency (IEA) has estimated that the developing countries will need to double their installed generation capacity in order to meet their growing demand for power by the year 2020. In the International Energy Outlook (IEO) 2009[1], the total world consumption of marketed energy is projected to increase by 44% from 2006 to 2030.

Chen[2] conducted a case study in seven households (family farms) in the Meixian, Guangdong, South China region in 1994. The analysis showed that the three major components of this system functioned in harmony for the mutual benefit of these farmers and their environment. Pomelo (Citrus grandis) farming was the most profitable component of the system. Pomelo litter fall and pig dung were fed into the biogas digester underneath the pigsty. The digester supplied biogas as domestic fuel and sludge as fertilizer. Chickens were raised in the orchard where they fed on weeds and pests, and deposited excreta as fertilizer. Recycling of wastes improved soil texture, and thereby decreased input of chemical fertilizers. This system helped natural enemies function well in these case studies, and therefore decreased the application of pesticides. Serving as a key link between fruit farming and animal husbandry, biogas production alleviated the scarcity of rural energy in Meixian. Sgroi et al.[3] performed an analysis of biogas plant costs considering the cost involved of the three macro-categories that is biomass, plant installation and transport. They also studied the economic performances of biogas plants, while progressively altering two key variables. They considered electrical power capacity (in the 100–999 kW range) and several combinations of feeding mixtures of livestock waste and giant reed silage, so as to determine the most economically advantageous option for a given power capacity. Their results showed that the cost of biogas production is directly dependent upon the feedstock used, biomass supply cost and biogas plant size. Drosg et al.[4] have discussed in details the different feedstock analysis methodologies that include analysis of pH, total solids/dry matter, volatile solids/organic dry matter, chemical oxygen demand, total Kjeldahl nitrogen, ammonia nitrogen and biochemical methane potential. They have also described additional analysis of biogas feedstock that include total organic carbon, trace element analysis, sulphur, phosphorous and continuous anaerobic fermentation tests. They have stated important details for feedstock evaluation. Firstly, different approaches for estimating a realistic energy recovery potential are laid out. Secondly, the effect of the carbon oxidation state in a feedstock on methane concentration in the produced biogas is described. Thirdly, the availability of macro- and micronutrients is estimated and a short summary of possible inhibitory or toxic components in biogas feedstocks has been given. Bhatti et al.[5] have conducted exergy analysis of photovoltaic thermal integrated biogas system for the month of January for Srinagar (Kashmir), India. It was concluded that the system consisting of partially covered flat plate collectors as discussed in case (ii) is highly sustainable and efficient for functioning in harsh cold climatic conditions that exists in Srinagar (Kashmir), India because it produces both thermal as well as electrical energy simultaneously.

Usmani et al.[6] studied the performance of a greenhouse integrated biogas plant in order to reduce the thermal loss to ambient in harsh cold . Due to the lower temperature, biogas production decreases drastically and may even stop. Thus, to enhance biogas production, a higher digester temperature than ambient temperature is required. Vinoth and Kasturi[7] had studied the solar greenhouse assisted biogas plant and they recommended the same for hilly regions recommended. They also concluded that in those hilly regions where average temperature remains below 37°C throughout the year their biogas- green house hybrid system may be successful.Wu et al.[8] had concluded in his study that higher biogas yield from anaerobic digestion process can be obtained when the biogas plant runs on a mixture of animal manure and vegetable/crop waste rather than on animal manure alone, and he has also stated that biogas production is considered the most suitable bioenergy technology in China. Steinfeld et al.[9] recommended that biogas can be produced from nearly all kinds of biological feedstock types, within these from the primary agricultural sectors and from various organic waste streams from the overall society. The largest resource is represented by animal manure and slurries from cattle and pig production units as well as from poultry, fish etc. In India, million tones of animal manure are produced every year. When untreated or poorly managed, animal manure becomes a major source of air and water pollution. Nutrient leaching, mainly nitrogen and phosphorus, ammonia evaporation and pathogen contamination are some of the major threats. The animal production sector is responsible for 18% of the overall green house gas emissions, measured in CO_2. Furthermore, 65% of anthropogenic nitrous oxide and 64% of anthropogenic ammonia emission originates from the world wide animal production sector. Agrahari and Tiwari[10] have designed and tested the performance of a portable floating type biogas plant made up of plastic having a volume capacity 0.018 m^3 for outdoor climatic condition. The experiment was conducted at IIT Delhi, New Delhi, India. In their work, a comparative study was done in between cow dung and kitchen waste for their biogas production capacity when 30 kg slurry was taken in batch system. During the experimental duration, the various parameters like temperature, solar radiation and relative humidity were measured; in addition, the constituent of biogas, pH, volume and rate of biogas production were analyzed at different level of temperature observation on daily basis. Physical and chemical analysis of biogas and slurry have also been carried out along with the comparison of other fuel sources which can be saved by the use of biogas plant.

Zhou and Lin[11] suggested that the slurry and residues from the biogas process can be used as an efficient organic fertilizer which can effectively replace the chemical fertilizers that are widely used in farms across the world.

2. FEEDSTOCKS FOR BIOGAS PRODUCTION

A wide range of biomass types can be used as substrates or feedstock for the production of biogas. The most common biomass categories that are used are shown in Fig. 1. and have also been listed below:

- Dedicated energy crops (e.g. maize, sorghum, clover)
- Digestible organic wastes from food and agro industries (vegetable and animal origin)
- Organic fraction of municipal waste from catering (vegetable and animal origin)
- Agricultural residues and by-products
- Animal manure and slurry
- Sewage sludge

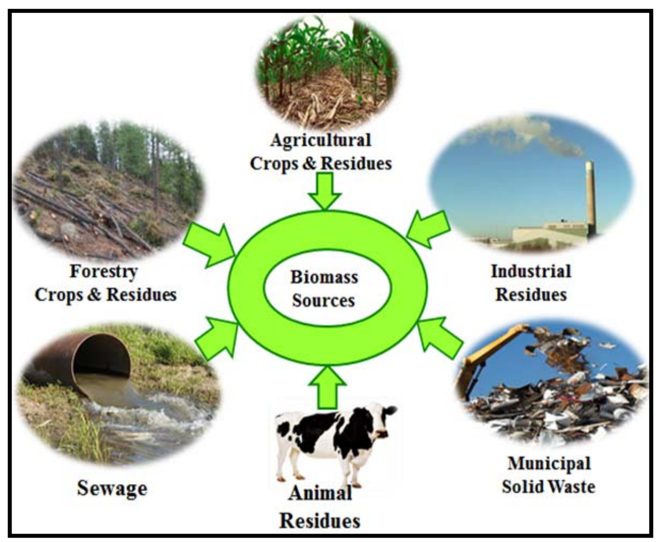

Fig. 1: Substrates for Anaerobic Digestion

Feedstock like : cow dung, kitchen waste, water hyacinth, water chestnut (peels and stems), dry leaves, leftover food from hostels, community centre's and banquet halls, leftover fruit waste collected from juice shops, garlands and flowers from temples, weddings and parties etc, green leafy vegetable leftover from mandi etc serve as a good source for biogas production. A biogas plant can easily thrive throughout the year on organic feedstock that is freely available and in abundance without incurring any additional expenditure for their production. The other alternative method that has been practiced to ensure feedstock supply throughout the year is to store the feedstock either in bunker silos (for solid feedstock) which were originally developed to store animal fodder but can also be used for this purpose and liquid feedstock can be stored in storage tanks (e.g. liquid manure and slurries).

In households located in rural or urban areas, a large amount of kitchen waste is obtained daily which can be utilized for better purposes. The major concern behind effective management of such solid waste is to ensure minimal risk to human health and the environment. Another concern is to look for economically feasible solutions. One of the methods is to convert this kitchen waste into energy by making it undergo anaerobic digestion. Kitchen waste originates from soil and ultimately reaches the same in the form of digestate which is a by product of anaerobic digestion.

Another benefit of carrying out anaerobic digestion of kitchen waste is that the feedstock is available free of cost throughout the year. Also, this method would result in maximum energy recovery and lesser discharge making it an economically viable option.

Presence of aquatic plants is essential for the conversion of solar energy into chemical energy which is utilised for the development of aquatic fauna like fish, prawns, etc. and for continuous addition of oxygen to water during photosynthesis. If aquatic plants due to over growth make the water bodies unfit and take the shape of noxious aquatic vegetation, these may be called as aquatic weeds for example Water Hyacinth. Aquatic weeds are those unwanted plants, growing in water that complete at least a part of their life cycle in water. These aquatic weeds when die and decay may result in the pollution of the drinking water. Besides providing convenient breeding sites for mosquitoes, snails and other animals of medical and veterinary importance, they may also invade large areas impending the free movement and usage of water in irrigation systems and in fish culture. In India many rivers, irrigation canals, lakes both natural and man-made are choked by the explosive growth of Water Hyacinth an aquatic weed, resulting in enormous direct losses.

The ‘Singhara phal’ or water chestnut is economically important aquatic crop grown in different parts of India as well as south – east Asian countries like Bangladesh, Thailand, Myanmar. It is an annual, rooted aquatic plant with rosettes of floating leaves as well as submerged leaves. Floating leaves are simple with dentate margin while submerged leaves are pinnately compound and filiform lobes with smooth margin. This aquatic herb is generally 0.5 to 2 m long but can grow upto 5 to 6 m, depending upon the depth of water , to keep the crown of rosette leaves afloat. The flowers are white and open above the surface of water. After pollination two – spine fruits 15 to 35 g in size grow under water. In states like Bihar, Uttar Pradesh and West Bengal this crop is popularly grown mainly in the depressions on the sides of railway tracks or in depressions on the sides of highways. The dry matter content has been found to be 11.5(+/-)0.15% for green variety and 17.3(+/-)1.22 % for the red variety of Water chestnut. Since the dry matter content is lower than 20% hence it has been considered as an important feedstock source for anaerobic digestion.

3. BENEFITS OF BIOGAS TECHNOLOGY TO THE FARMERS

- Additional income for the farmers involved - production of feedstock in combination with operation of biogas plants makes biogas technologies economically attractive for farmers and provides them with additional income. The farmers get also a new and important social function as energy providers and waste treatment operators.
- Digestate is an excellent fertiliser - A biogas plant is not only a supplier of energy. The digested substrate, usually named digestate, is a valuable soil fertilizer, rich in nitrogen, phosphorus, potassium and micronutrients, which can be applied on soils with the usual equipment for application of liquid manure. Compared to raw animal manure, digestate has improved fertilizer efficiency due to higher homogeneity and nutrient availability, better C/N ratio and significantly reduced odours.
- Closed Nutrient Cycle - From the production of feedstock to the application of digestate as fertiliser, biogas provides a closed nutrient and carbon cycle. Methane (CH_4) is used for energy production and carbon dioxide (CO_2) is released in the atmosphere. CO_2 is again used by the vegetation during photosynthesis. Some carbon compounds remain in the digestate, when the digestate is applied as fertiliser it improves the carbon content of the soil. The digestate produced during biogas production can perfectly replace chemical fertilisers, which are produced with the consumption of large amounts of fossil energy.
- Reduced odours and flies - Storage and application of liquid manure, animal dung and many organic wastes are sources of persistent, unpleasant odours and attract flies. Anaerobic Digestion reduces these odours by up to 80% . Digestate is almost odourless and the remaining ammonia odours disappear shortly after application as fertiliser.

Many modern biogas plants operate at thermophilic process temperatures (43° C – 55° C) as the thermophilic process provides many advantages, compared to mesophilic and psychrophilic processes:

- Effective destruction of pathogens.
- Higher growth rate of methanogenic bacteria at higher temperature.
- Reduced retention time, making the process faster and more efficient.

- Improved digestibility and availability of substrates.
- Better degradation of solid substrates and better substrate utilisation.
- Better possibility for separating liquid and solid fractions

4. MONTHLY FEEDSTOCK AVAILABILITY IN AN YEAR

The feedstock like : cow dung, kitchen waste, water hyacinth, water chestnut (peels and stems), dry leaves, leftover food from hostels, community centre's and banquet halls, leftover fruit waste collected from juice shops, garlands and flowers from temples, weddings and parties etc, green leafy vegetable leftover from mandi etc serve as a good source for biogas production. Following are the reasons why they serve as an excellent source for biogas production:

- They are abundantly and freely available.
- Their production and cultivation takes up no extra land.
- It will save wood, which is increasingly scarce.
- They can be converted into a solid or gaseous fuel.
- Overall, it does not increase atmospheric CO_2.
- Production on a larger scale creates more local jobs

A biogas plant can easily thrive throughout the year on organic feedstock without any additional expenditure for their production as they are freely and abundantly available. The other alternative method that has been practiced to ensure feedstock supply throughout the year is to store the feedstock either in bunker silos (for solid feedstock) which were originally developed to store animal fodder but can also be used for this purpose and liquid feedstock can be stored in storage tanks (e.g. liquid manure and slurries).

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About the Author

Ms. Jasleen Bhatti is a research scholar at Centre for energy studies, Indian Institute of Technology Delhi, India. Ms. Bhatti was born on July 2, 1982 at New Delhi, India. She has completed her Masters in Analytical Chemistry from Dr. B. R. Ambedkar University, Agra (U.P.) India in 2007. Thereafter, she worked with Genpact, American Express and Foundation for Innovation and Technology Transfer at I.I.T Delhi, India. She has over 4 years of rich experience in industrial research and operations. She joined as a Research Scholar under the supervision of Prof. G. N. Tiwari in December 2011. Her fields of interest include environment and development, socio economic impact assessment, sustainable energy, solar energy and its applications and biogas issues.

Dr. Gopal Nath Tiwari was born on July 1, 1951 at Adarsh Nagar, Sagarpali, Ballia (U.P.) in India. He has completed his M.Sc. (Physics) and Ph.D in 1972 and 1976 from Banaras Hindu University, Varanasi (U.P.), India. He is recipient of JRF, SRF and PDF from CSIR, Govt. of India during 1972-1978. He joined as a Research Associate at I.I.T Delhi, New Delhi in 1978. He is holding a position of Professor at Centre for Energy Studies, I.I.T Delhi, New Delhi since 1997. He had been energy expert in University of Papua New Guinea, Port Morshy, PNG during 1987-89. Dr. Tiwari was visiting European Fellow at University of Ulster, Northern Ireland (UK) during 1993 for six months. He has visited many other countries namely Canada, USA, Italy, Australia for short terms as an energy expert. He is recipient of National Hari Om Ashram Prerit S.S. Bhatnagar Award in 1982 for his seminal contribution in the field of solar distillation. Dr. Tiwari has published to his credit more than five hundred research papers in different National and International Journals. He is the author of eight text and reference books on solar energy, greenhouse, passive heating/cooling, Renewable Energy Resources etc. He had been nominated for International IDEA Award for his work on solar distillation in 1992. Dr. Tiwari has supervised more than seventy five Ph.D students in various research areas of interest. His current areas of research interest are Solar Energy and its applications in solar distillation, passive heating/cooling of building, controlled environment greenhouse, aquaculture, water/air heating system, crop production and drying, renewable energy resources, energy analysis of all systems, techno-economic analysis, hybrid PV/thermal systems, clean environment and rural energy etc.