Advancement in Biogas Digester

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Abstract Biogas is a renewable energy source with different production pathways and various excellent opportunities to use. Biogas refers to a gas produced by anaerobic digestion (AD) or fermentation of organic matter including manure, sewage sludge, municipal solid waste, biodegradable waste, energy crops, or other biodegradable feedstock. Biogas is comprised primarily of methane and carbon dioxide. In this review, we discussed the worldwide status of biogas production, history of the biogas digester, classification of biogas digester, and their advantages and disadvantages. The government policies on the use of kitchen-waste-based digesters and the social and environmental effects of the digesters are also discussed. More subsidies need to be given and more initiatives need to be taken by the government. The government has many policies for biogas digester plants; however, lack of proper awareness among people inhibits the adaptation of technology.

Keywords Biogas digester · Environmental effect · Government policies · Subsidies

1 Introduction

Due to increasing prices of fossil fuels and taxes on energy sources, we are compelled to find alternative, clean and economical sources of energy. This has currently become a major apprehension for the economies of nations. In addition, economic prosperity and quality of life are linked in most countries to per capita

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energy consumption, which is a great determinant and indicator of economical development. The demand for energy is a major reason for extensive climate change, resource use, and also restricts the living standards of humans. By the time fuel and fertilizer reach rural areas, the end price is relatively expensive due to high carrying costs, leaving people to find alternative resources other than oil. Wood is used as the conventional source of fuel to produce energy for the household requirements of 4.3 billion people of Asia (Rajendran et al. 2012).

Several traditional methods have been used to utilize energy capacity embedded in carbon neutral biomass sources and anaerobic digestion (AD) is one of them. AD is a natural process whereby bacteria existing in oxygen-free environments decompose organic matter. In AD, organic material is stabilized and gaseous byproducts, primarily methane (CH_4) and carbon dioxide (CO_2), are released. Anaerobic digesters are designed to run in either mesophilic (20–45 °C) or thermophilic (45–60 °C) temperature. However, methanogenesis is also probable in low temperature (<20 °C) (Balasubramaniyam et al. 2008). Today, farm-based manure facilities are perhaps the most common use of the AD-technology. Six to eight million family-sized low-technology digesters are used in the Far East (People's Republic of China and India) to give biogas for lighting and cooking. There are now over 800 farm-based digesters in service in Europe and North America (Simon 1999).

Biogas typically refers to a gas produced by the breakdown of organic matter in the absence of oxygen. It is a renewable energy source. Furthermore, biogas can be produced from regionally available raw materials such as recycled waste and is environmentally friendly.[1] A biogas digester, also known as a methane digester, is a piece of equipment that can turn organic waste into usable fuel. In addition to providing a source of renewable fuel, biogas digesters also provide low-cost fuel to people in poverty, and help to use waste materials effectively, which would otherwise be discarded. The biogas digester relies on bacterial decomposition of biomass—waste material which is biological in origin, ranging from kitchen scraps to cow dung.[2] The main part of a biogas system is a large tank, or digester. Inside this tank, bacteria convert organic waste into methane gas through the process of AD. Each day, the operator of a biogas system feeds the digester with household by-products such as market waste, kitchen waste, and manure from livestock. The methane gas produced in a biogas system may be used for cooking, lighting, and other energy needs. Waste that has been fully digested exits the biogas system in the form of organic fertilizer.[3] New technologies in the field of biogas digesters include bag-type biogas digester plants, Vacvina biogas digester, and plastic-drum type biogas digesters.

The waste generation rate is increasing in India by 1.33 times per year as shown in recent studies. By 2047, India will produce around 260 million tons of

[1] www.en.wikipedia.org/wiki/Biogas_digester.

[2] www.wisegeek.com/what-is-a-biogas-digester.htm.

[3] www.simgas.com/advantages-of-biogas/how-does-biogas-work/item46.

solid waste and for disposal of this waste, a total land area of around 1400 ha km^2 is required. The rate of generation of waste is really impossible to reduce and it is also impossible to supply such a big land area for its disposal. In India, for solid waste management, approx. Rs. 1500 crore is disbursed for its overall management (Bansal 2013).

In this chapter is discussed the efforts made toward the present status of biogas digester, government policy, and market growth in India. The Indian Government started a scheme "Biogas based Distributed/Grid Power Generation Programme" from 2005–2006 (January 4, 2006) with a vision to promote biogas-based power generation, particularly in the small capacity range, based on the accessibility of large amounts of animal wastes and wastes from forestry, rural-based industries (agro/food processing), kitchen wastes, etc.

2 Historical Development in Biogas Digesters

Biogas utilization from AD appears to have a long history. Evidence suggests that biogas was used even 3000 years ago for heating bath water in Assyria. As reported by Marco Polo, the ancient Chinese literature mentions covered sewage tanks built for biogas production some 2000–3000 years ago.[4] The technology of biogas production dates back to a long time. In the seventeenth century, Jan Baptita Van Helmont first determined that flammable gases could develop from putrefying organic matter. In 1776, Count Alessandro Volta suggested that there was a direct relation between the quantity of decomposing organic matter and the quantity of flammable gas generated. In 1808, Sir Humphry Davy determined that methane exists in the gases generated during the AD of cattle dung.[5] In 1859, the first sewage plant in modern times was built in Bombay. In 1895 this concept was brought to the UK. The gas produced was used to light street lamps. The arrangement was developed in the UK and Germany in the early 1900s for the management of sewage. The gas produced was sometimes used as a source of energy, especially during the Second World War. Since then, a number of sewage plants drove vehicles on biogas. In the 1930s, the use of farm manure to generate methane was again developed in Bombay. Only in the early 1960s, it was developed for utilization by Indian villagers by the Khadi and Villages Industries Commission (KVIC). The design used a floating gas steel drum and formed the basis of an ongoing Indian Government program to reach out to villagers for providing them with fuel for cooking.[6] In India, a lot of important work on biogas has been done. But only in more recent times did these developments reach the other parts of the world when

[4]http://www.energsustainsoc.com/content/4/1/10.

[5]http://extension.psu.edu/natural-resources/energy/waste-to-energy/resources/biogas/links/history-of-anaerobic-digestion/a-short-history-of-anaerobic-digestion.

[6]http://www.kingdombio.com/history1.html.

almost every nation became attracted to the subject. In India since 1939, research on biogas was undertaken but it was not until 1951 that there was a real start in its use. However, the developments of biogas plants were still slow and unsatisfactory until 1961 when the Indian Khadi and Village Industries Commission took over. About 7000 biogas plants had already been installed by 1973–1974, and the number more than doubled by 1974–1975. The development in the design, construction, and operation of practical digesters was one reason for this increase in the number of biogas plants. Additionally, enough knowledge was obtained for the utilization of the gas not only for cooking but also for lighting and running engines. The involvement of competent scientists can also be attributed for the success. The wide-ranging work on biogas in India may be classified into three stages: experimentation, 1937–1950; pilot studies, 1950–1963; and fully operational stage, from 1964.[7] In 2007, there were 26.5 million biogas plants in China. Meanwhile, in 1999 there were over three million family-sized biogas plants in India. By the end of 2007, the Indian government had given subsidy for construction of nearly four million family-sized biogas plants. Since 1981–1982, the National Project on Biogas Development (NPBD) has run and promotes its own digester designs while providing monetary support and different training and development programs. Subsidies from the State and Central governments to install household bioreactors ranged from 30 to 100 % in the 1980s–1990s (Bond and Templeton 2011).

3 Classification of Biogas Digester

Biogas plants are classified in various types. The most important types of biogas plants are described below:

I. Fixed-dome biogas plants
II. Floating-drum biogas plants
III. Balloon biogas plants
IV. Horizontal biogas plants
V. Earth-pit biogas plants
VI. Ferro-cement biogas plants

The two most familiar types in developing countries are the fixed-dome biogas plants and the floating-drum biogas plants. Typical designs in industrialized countries and appropriate design selection criteria have also been considered (Hoerz et al. 2008).

3.1 Fixed-Dome Biogas Plant

The fixed-dome digesters are typically constructed underground. The amount of substrate available per day and the number of heads in the household are the two

[7] http://www.biogastechnologyphils.com/index.php/historical-devt.

main important parameters that determine the size of the digester. The fixed-dome type digesters are also called “Chinese” or “hydraulic” digesters. The digester is filled with inlet pipe until the level reaches the bottom level of the expansion chamber. The produced biogas accumulates in the upper part of the digester, which is called the storage part. The difference between slurry inside the digester and the expansion chamber creates a gas pressure. The collected gas requires space and presses a part of the substrate into an expansion chamber. The slurry flows back into the digester immediately after the gas is released (Rajendran et al. 2012). On-farm biogas plants collect cow dung from adapted cattle sheds, mix it with water, and channel it into fermentation pits. The resulting gas is fed directly to the farmer’s household to provide energy for cooking, laundry, and lighting.[8] A gas handling system removes biogas from the digester and transports it to the end-use, such as an engine or flange. Gas handling includes: piping, gas pump or blower, gas meter, pressure regulator, and condensate drain. Biogas produced in the digester is trapped under an airtight cover placed over the digester. The biogas is removed by pulling a slight vacuum on the collection pipe (e.g., by connecting a gas pump/blower to the end of the pipe), which draws the collected gas from under the cover. A gas meter is used to monitor the gas flow rate. Sometimes a gas scrubber is needed to clean or “scrub” the biogas of corrosive compounds contained in the biogas (e.g., hydrogen sulfide). Warm biogas cools as it travels through the piping and water vapor in the gas condenses. A condensate drain removes the condensate produced (Seadi et al. 2013). This biogas produced is further processed so that the carbon dioxide and hydrogen sulfide gases are removed. The result is a gas consisting mostly of methane. This is similar to natural gas obtained from the oil and gas fields. By using compressors in a bottling plant, methane and carbon dioxide gases can be stored under high pressure in cylinders. These gases can be utilized in other industrial applications. Much of the biogas can be used as fuel in vehicles, electrical power generators, and for other heating purposes.

The sketch of the plant with a simple formula for the calculations of its volume is shown in Fig. 1.

The equations used in deriving the volume of the fixed-dome biogas digester are given as (Seadi et al. 2013);

$$v_1 = \frac{\pi}{6} f_1 (3r^2 + f_1^2) \tag{1}$$

$$v_2 = \pi r^2 H_1 \tag{2}$$

$$v_3 = \frac{\pi}{6} f_2 (3r^2 + f_2^2) \tag{3}$$

$$\text{Volume of Digester} = v_1 + v_2 + v_3 \tag{4}$$

[8] http://practicalaction.org/biogas_christmas.

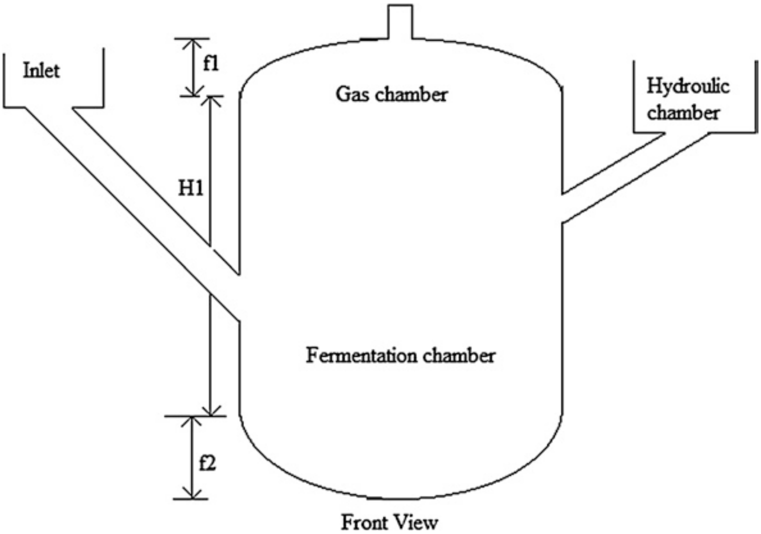


Fig. 1 Fixed-dome biogas plant (Seadi et al. 2013)

where

v_1	volume of upper arc (gas chamber).
v_2	volume of fermentation chamber.
v_3	volume of lower arc.
r	radius of cylinder.
H_1	height of fermentation chamber.
f_1 and f_2	height of upper and lower arcs.

Figure 2 shows the schematic diagram of a fixed-dome type biogas digester. The various dimensions are marked. Figure 3 is adapted from Fig. 2 for calculation purpose. The link between h, r, and R is the included angle of the fixed-dome biogas digester. The half-angle φ determines the width of the fixed-dome biogas digester.

$$\tan \varnothing = \frac{r}{R - h} \tag{5}$$

The gas storage volume (V) of an underground biogas plant is a segment of a dome, or a cap cut from the top of a dome of radius (R). The horizontal radius (r) of the base of the cap is related to the height (h) of the cap by[9]:

$$R^2 = r^2 + (R - h)^2 \tag{6}$$

[9]http://www.kingdombio.com/equations2.html.

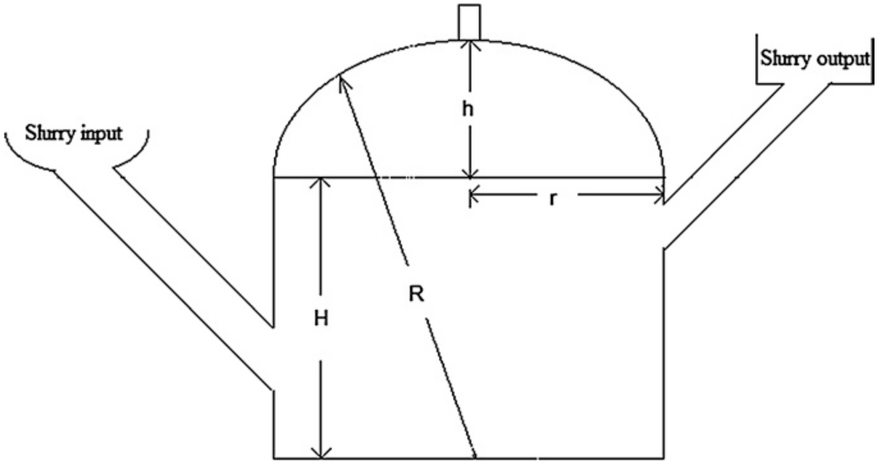
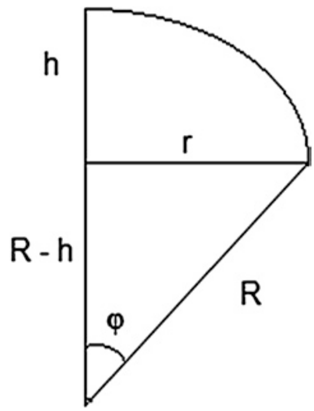


Fig. 2 Various parameters of fixed dome (http://www.kingdombio.com/ggcdraw.html)

Fig. 3 Half angle φ determining width of fixed dome (see footnote 10)



This gives:

$$h = R \pm \sqrt{R^2 + r^2} \tag{7}$$

Now:

$$V = 3\pi h^2 (3R - h) \tag{8}$$

Rearranging gives:

$$V = 6\pi h (3r^2 + h^2) \tag{9}$$

Advantages:

I. Low initial costs and long useful lifespan.
II. No moving or rusting parts involved.
III. The basic design is compact, saves space and is well insulated.
IV. Construction creates local employment.

Disadvantages:

I. Masonry gas-holders require special sealants and high technical skills for gas-tight construction.
II. Gas leaks occur frequently.
III. Fluctuating gas pressure complicates gas utilization.
IV. The amount of gas produced is not immediately visible.
V. Plant operation is not readily understandable.
VI. Fixed-dome plants need exact planning of levels.
VII. Excavation can be difficult and expensive in bedrock (Hoerz et al. 2008).

Fixed-dome biogas plants can be recommended only where construction can be supervised by experienced biogas technicians.

3.2 Floating-Drum Biogas Plants

The basic design consists of a drum that acts as the gas holder, a cylindrical tank that acts as the digestion chamber, a gas meter, a feed pit, and an outlet pit. The gas drum is slightly smaller than the tank opening (Istok 2013). It floats in the cylindrical top of the tank due to the internal gas pressure. This drum is like an upside-down pot and it floats on top of the digesting sludge and captures the gas. It is usually made of mild steel or sometimes fiberglass reinforced plastic (FRP) and High Density Polyethylene (HDPE) mixed material (Mostajir et al. 2013). The gas produced is trapped under this floating cover which rises and falls on a central guide. The pressure of the gas available depends on the weight of the gas holder per unit area and usually ranges from 4 to 8 cm of water pressure. The reactor wall and bottom are usually constructed of brick, although reinforced concrete is sometimes used. The reactor is fed semi-continuously (e.g. once a day) through an inlet pipe, and displaces an equal amount of slurry through an outlet pipe; the underground tank has large inlet and outlet pipe as waste material and fertilizer and the gas pipe comes out of the top of the floating drum (Hagegard 2008). Construction costs vary according to ambient temperature, the size of biogas digester, the manure management system used at the farm, and other factors. The cost of a mild steel gas-holder is approximately 40–50 % of the total cost of the plant. More recently, the steel drum has been replaced by FRP to overcome the problem of corrosion. However, FRP gas-holders are 6–12 % more expensive than the steel drum (Biogas 2007). Gas separation can be achieved by the biogas plant by employing membrane for separation of CH_4 and CO_2. The membrane gas separation-based process aims at upgrading the biogas to substitute natural gas using low pressure

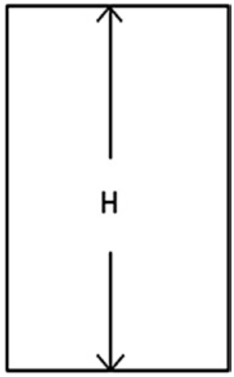


Fig. 4 Depth of the pit (see footnote 13)

(up to 3 bars) and distributing the substitute natural gas in the natural gas network. The by-product of the membrane gas separation process is a stream rich in CO_2 which could be liquefied to produce pure, industrial CO_2. After liquefaction, the remaining biogas components, which include CH_4, are recycled into the membrane gas separation process, thereby minimizing the loss of biogas. Both gases have high industrial value. Bio-methane also known as SNG has been used as a substitute for vehicle fuel and can also be used to produce electricity (Kalambe et al. 2012). For this method, gas scrubbers or air scrubbers are used, wherein H_2S is absorbed from the biogas. This kind of installation consists of one or more gas scrubbers (scrubbing stages). Inside the air scrubber, the biogas is brought in contact with water out of the aeration tank, which is circulated once over the air scrubbers and re-conducted into the aeration tank. The H_2S absorbed will be oxidated in the aeration tank. For this biological air scrubbing technique, the gas scrubbers are preferably installed in the direct neighborhood of the aeration tanks.[10] 5 m^3 biogas plants require 19 kg cow dung (1 or 2 cows) and 47 l of water everyday. One cow gives 10 kg cow dung per day and 1 kg cow dung produces 0.34 m^3 gases. So 1 m^3 biogas plant requires 3 kg cow dung per day. 1 m^3 biogas can be used to cook three meals for a family of 5–6 heads. 1 m^3 biogas can be used to light 60–100 W of electric bulbs for 6 h. It is equivalent to fuel replacement of 0.7 kg of petrol.[11]

Figure 4 shows the depth of the pit of a floating-drum type biogas digester. Figure 5 shows the diameter of the base of the pit of the digester. The internal volume (V) of a floating-drum biogas plant can be calculated using the volume of a cylinder, where d is the diameter of the pit and H the depth of the pit.[12]

$$V = \left(\frac{\pi d^2}{4}\right) \times H \tag{10}$$

[10]http://task.be/biogasdesulfurization.aspx.

[11]http://www.appropedia.org/Biogas_as_fuel.

[12]http://www.kingdombio.com/equation1.html.

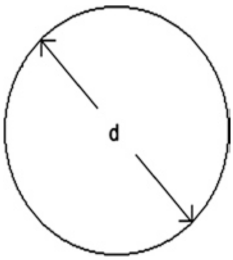


Fig. 5 Diameter of the base of pit (see footnote 13)

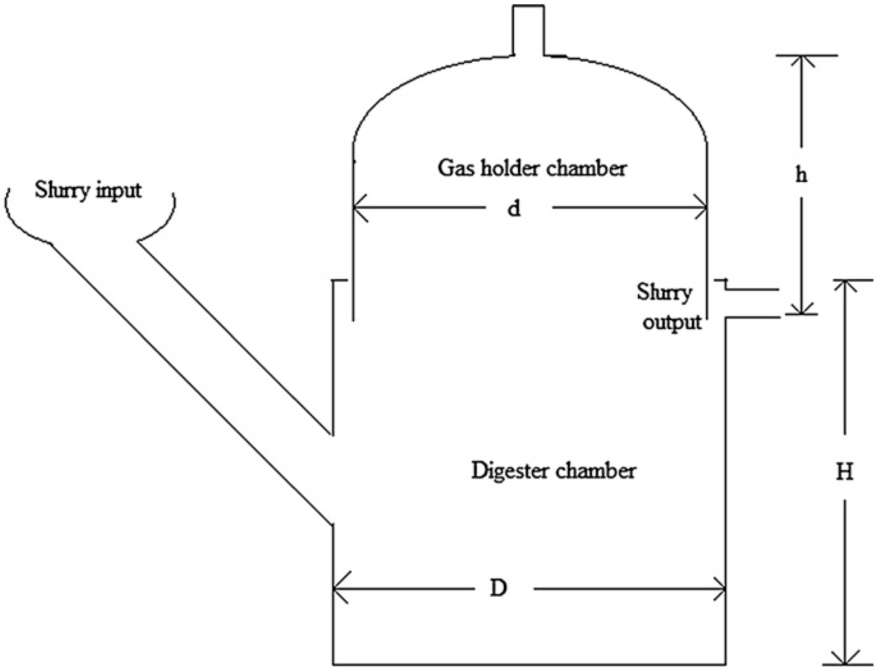


Fig. 6 Floating-drum type bio gas digester (see footnote 14)

Figure 6 shows that the internal volume of the floating drum can be calculated in the same way, with *d* as the diameter of the drum and *H* the height of the drum.[13]

D the diameter of the digester.
H the height of the digester/digester pit.
h the height of the gas-holder.
d the diameter of the gas-holder.

[13]http://www.kingdombio.com/floatdrum.html.

3.3 Retention Time

The retention time R is the time that the slurry requires to stay in the digester pit for complete digestion by bacteria. For continuous digester systems, the daily feed rate (v) is arrived at by dividing the digester volume (v_d) with the slurry retention time (R) (Kuria and Maringa 2008).

thus

$$V = \frac{v_d}{R} \tag{11}$$

The retention time is dependent on the prevailing temperature in a digester and on the type of substrate used. Most biogas digesters operate in the mesophilic temperature range (20° < t < 40 °C). For liquid manure undergoing fermentation in this temperature range (Bavutti et al. 2014; SNV Domestic Biogas 2011),

The following approximate retention times apply:

Liquid cow manure 20–30 days
Liquid pig manure 15–25 days
Liquid chicken droppings 20–40 days
Animal manure mixed with plant material: 50–80 days

3.4 Dimensioning

In determining the dimensions of digester, the simplifying assumption was made here that the diameter of the digester (D) is equal to its height (H). A clearance gap of 20 mm between the digester pit and the gas drum was adopted as adequate to allow free rotation of the gas drum, without allowing much leakage of the generated gas. The volume of such a digester pit is given by Kuria and Maringa (2008):

$$V_d = \frac{\pi D^2 H}{4} \tag{12}$$

Since H nearly equals D, it becomes:

$$V_d = \frac{\pi D^3}{4} \tag{13}$$

From which the diameter of the digester is obtained as:

$$D = \frac{\sqrt[3]{4} V_d}{\pi} \tag{14}$$

Taking the gas-holder/digester radial clearance to be 20 mm, gives a diameter (d) of the gas-holder of:

$$d = (D - 0.04) = \sqrt[3]{(4 V_d/\pi - 0.04)} m \tag{15}$$

Given a gas-holder volume (V_g), the height (h) of the gas holder is therefore given as

$$h = \frac{4V_g}{\pi d^2} \tag{16}$$

The important parameters for gas to standard temperature and pressure (STP) conversion are the biogas temperature and pressure, temperature of anaerobic environment and ambient temperature and pressure. Most of the research in the field of AD simply quotes gas production volumes without mentioning any correction applied to standard conditions (Parajuli 2011). A "floating drum" storage offers a good, simple way of measuring gas production. Just the change in height of the drum is recorded and volume of gas = area × height. Pressure and volume of any gas are related by $p_1 v_1 = p_2 v_2$, where p is pressure, v is volume, and 1 represents initial conditions and 2, the final conditions. Mass and volume are related by density, where Density = Mass/Volume, and the density of biogas is about 1.18 kg/m^3.[14]

Advantages:

I. Floating-drum biogas plants are easy to understand and operate.
II. Floating-drum biogas plants provide gas at a constant pressure.
III. The stored gas-volume is immediately recognizable by the position of the drum.
IV. Gas-tightness is no problem.
V. Provided the gas holder is derusted and painted regularly.

Disadvantages:

I. The steel drum is relatively expensive and maintenance-intensive.
II. Removing rust and painting has to be carried out regularly.
III. The lifetime of the drum is short (up to 15 years; in tropical coastal regions about five years) (Hoerz et al. 2008).

3.5 Balloon Biogas Plants

A balloon plant consists of a heat-sealed plastic or rubber bag (balloon), combining digester and gas-holder. The gas is stored in the upper part of the balloon. The inlet and outlet are attached directly to the skin of the balloon. The gas pressure can be increased by placing weights on the balloon. If the gas pressure exceeds a limit that the balloon can withstand, it may damage the skin. Therefore, safety valves are required. If higher gas pressures are needed, a gas pump is required. Since the material has to be weather and UV resistant, specially stabilized, reinforced plastic or synthetic caoutchouc is given preference. Other materials that have been used successfully include RMP (red mud plastic), Trevira, and butyl. The useful lifespan

[14]http://biogas.Wikispaces.com/Pressure-Volumecalculations.

Fig. 7 Balloon digester as seen in Costa Rica (see footnote 16)

usually does not exceed 2–5 years (Hoerz et al. 2008). The bag-type plant is manufactured with high-strength PVC-polyester fabric and other compounds. The bag system can be used with low-pressure stoves and lamps (Fig. 7).[15]

Advantages:

I. Low cost.
II. Ease of transportation.
III. Low construction sophistication.
IV. High digester temperature.
V. Shallow installation suitable for use in areas with a high groundwater table.
VI. Uncomplicated cleaning, emptying and maintenance.
VII. Difficult substrates like water hyacinths can be used.

Disadvantages:

I. Low gas pressure may require gas pumps.
II. Scum cannot be removed during operation.

[15]http://www.build-a-biogas-plant.com/Types-of-Biogas-Designs.html.

III. The plastic balloon has a relatively short useful lifespan and is susceptible to mechanical damage and usually not available locally.
IV. Local craftsmen are rarely in a position to repair a damaged balloon (Hoerz et al. 2008).

Balloon biogas plants are recommended, if local repair is or can be made possible and the cost advantage is substantial.

3.6 Horizontal Biogas Plants

Horizontal biogas plants consist of a container to hold the slurry, a ‘scrubber’ to reduce the carbon dioxide (CO_2) and sulfur dioxide (SO_2) content in the biogas, and a storage container to hold the gas (Figs. 8 and 9) (Forst 2002). Horizontal biogas digester plants are usually chosen when shallow installation is called for (groundwater, rock). They are made of masonry or concrete (Hoerz et al. 2008).

Advantage:
I. Shallow construction despite large slurry space.

Disadvantage:
I. Problems with gas-space leakage, difficult elimination of scum (Hoerz et al. 2008).

Fig. 8 Horizontal biogas plants (Forst 2002)

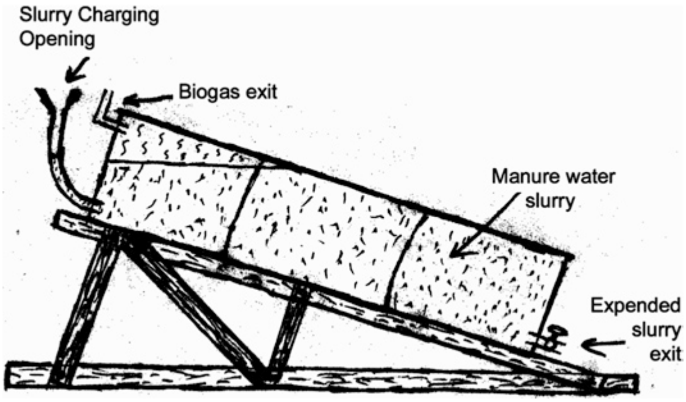


Fig. 9 Schematic diagram of horizontal biogas plants (Forst 2002)

3.7 Earth-Pit Biogas Plants

Masonry digesters are not necessary in stable soil. It is sufficient to line the pit with a thin layer of cement in order to prevent seepage. The edge of the pit is reinforced with a ring of masonry that also serves as an anchorage for the gas-holder. The gas-holder can be made of metal or plastic sheeting. If plastic sheeting is used, it must be attached to a quadratic wooden frame that extends down into the slurry and is anchored in place to counter its buoyancy. The requisite gas pressure is achieved by placing weights on the gas-holder. An overflow point in the peripheral wall serves as the slurry outlet (Hoerz et al. 2008). This is the new toilet system which works as a biogas plant, which has been designed and based on Earth Bag Shelter. It consists of Digester, Slurry Outlet, and Inlet. Any fermentable organic matter is mixed with water in the inlet tank and introduced from the inlet pipe. It is destroyed by bacteria under anaerobic conditions in the digester. Inflammable methane gas is produced at this stage. The gas pushes the fermented mix out to the slurry outlet and it can be used as good fertilizer. Biogas plants are built all over the world (Fig. 10) (Geiger 2010).

Advantages:
I. Low cost of installation (as little as 20 % of a floating-drum plant).
II. The high potential for self-help approaches.

Disadvantages:
I. Short useful life; serviceable only in suitable.
II. Impermeable types of soil.

Earth-pit biogas plants can only be recommended for installation in impermeable soil located above the groundwater table. Their construction is particularly inexpensive in connection with plastic sheet gas-holders (Hoerz et al. 2008).

Fig. 10 Earth bag biogas plant (Geiger 2010)

3.8 Ferro-Cement Biogas Plants

Ferro-cement biogas plants for construction can be applied either as a self-supporting shell or an earth-pit lining. The vessel is usually cylindrical. Very small plants (Volume under 6 m^3) can be prefabricated. As in the case of a fixed-dome plant, the ferro-cement gas-holder requires special sealing measures (Hoerz et al. 2008). Appropriate models of family type biogas plants should be selected on the basis of preference of the beneficiaries and considering technical requirements, such as location, distance between the kitchen and cattle shed, availability of water and feedstock like dung, kitchen, loose and leafy biomass, sanitary, and other biomass wastes. Approved models for such plants are available for 1–10 m^3 capacities for fixed-dome and floating-dome type plants. The commonly used capacities of these models are 1–4 m^3. Pre-fabricated models of biogas plants are also available based on HDPE, FRP, and Reinforced Cement Concrete (RCC) material in addition to ferro-cement and brick-masonry biogas digester plants (Fig. 11). The digesters have a volume of 4–10 m^3 and are made of ferro-cement. The gasholder

Fig. 11 Ferro-cement biogas plants (Construction of a biogas plant in Mirpurkhas Sindh Pakistan 2012)

is made of FRP coated steel for bigger plants or a drum made of FRP for smaller plants (Construction of a biogas plant in Mirpurkhas Sindh Pakistan 2012).

Advantages:
I. Low cost of construction.
II. Especially in comparison with potentially high cost of masonry for alternative plants.
III. Mass production possible.
IV. Low material input.

Disadvantages:
I. Substantial consumption of essentially good-quality cement.
II. Workmanship must meet high quality standards.
III. Uses substantial amounts of expensive wire mesh.
IV. Construction technique not yet adequately time-tested.
V. Special sealing measures for the gas-holder are necessary.

Ferro-cement biogas plants are only recommended in cases where special ferro-cement is available (Hoerz et al. 2008).

4 Some Popular Indian Biogas Designs Approved by MNRES and KVIC the Nodal Agency for Biogas

The most important types of biogas plants used in India are:

I. Janta Fixed-Dome type
II. KVIC Floating-Drum type
III. Deenbandhu fixed-dome type

4.1 Janta Fixed-Dome Type Biogas Plant

This type of biogas plant is economical in design. Janta Fixed-dome type's capacities are 1–6 m^3. It works with the constant volume principle. The main structure is made of brick and cement masonry. This type of plant does not have any moving parts so it is safe from wear and tear. The operating pressure varies from 0 to 100 cm of water column. It is also known as Janta model (Fig. 12).[16]

The foundation is a well-compacted base of the digester constructed of brick ballast and cement concrete (CC). The upper portion of the foundation has a smooth plaster surface. The digester is a cylindrical tank resting on the foundation.

[16] http://mechanicalinventions.blogspot.in/2014/06/fixed-dome-type-janata-model-biogas-plant-construction.html.

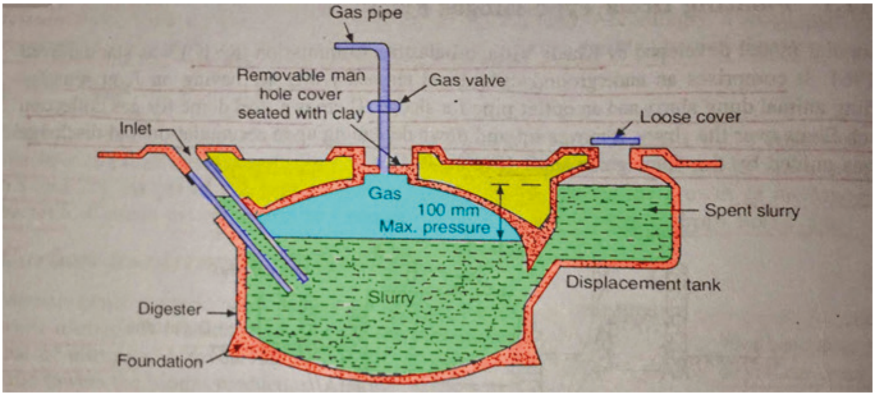


Fig. 12 Janta fixed-dome type biogas digester

The top surface of the foundation serves as the bottom of the digester. The digester (fermentation chamber) is constructed with bricks and cement mortar. The digester wall has two small rectangular openings in the middle, situated diametrically opposite, known as inlet and outlet gate, one for the inflow of fresh slurry and the other for the outflow of digested slurry. The digester of Janta BGP comprises the fermentation chamber (effective digester volume) and the gas storage chamber (GSC). The GSC is also cylindrical in shape and is the integral part of the digester and located just above the fermentation chamber. The GSC is designed to store 33 % (approx. 8 h) of the daily gas production from the plant. The GSC is constructed with bricks and cement mortar. The gas pressure in Janta model varies from a minimum of 0 cm water column (when the plant is completely empty) to a maximum of up to 90 cm of water column when the plant is completely full of biogas. The hemispherical shaped dome forms the cover (roof) of the digester and is constructed with brick and CC mixture, after which it is plastered with cement mortar. The dome is only an enclosed roof designed in such a way as to avoid steel reinforcement. The upper portion of the inlet chamber is in the shape of a bell mouth and constructed using bricks and cement mortar. Its outer wall is kept inclined to the cylindrical wall of the digester so that the feed material can flow easily into the digester by gravity. The bottom opening of the inlet chamber is connected to the inlet gate and the upper portion is much wider and known as inlet displacement chamber (IDC). The top opening of the inlet chamber is located close to the ground level to enable easy feeding of fresh slurry. The outlet chamber is a rectangular shaped chamber located opposite the inlet chamber. The bottom opening of the outlet chamber is connected to the outlet gate and the upper portion is much wider and known as outlet displacement chamber (ODC). The outlet chamber is constructed using bricks and cement mortar. The top opening of the outlet chamber is located close to the ground level to enable easy removal of the digested slurry through a discharge opening. The level of the discharge opening provided on the outer wall of the outlet chamber is kept at a somewhat lower level than the upper mouth of the inlet opening, as well as lower than the crown of the dome ceiling. This is to facilitate easy flow of the digested slurry out of the plant into the digested slurry pit and also to prevent reverse flow, either in the mixing tank through the inlet chamber or to go inside the gas outlet pipe and choke it. The biogas outlet pipe is fixed on the crown of the dome, which is made of a small length of GI pipe fitted with socket and a gate valve.[17]

Advantages:

I. The costs of a fixed-dome biogas plant are relatively low.
II. It is simple as no moving parts exist.
III. There are also no rusting steel parts and hence long life of the plant (20 years or more) can be expected.
IV. Fixed-dome plants are not easy to build.
V. They should only be built where construction can be supervised by experienced biogas technicians.

Disadvantage:

I. Due to the porosity and cracks, gas generated may leak.[18]

4.2 KVIC Floating-Drum Plant

The KVIC Model is a floating biogas holder semi-continuous-fed BGP and is of two types, viz. (i) vertical and (ii) horizontal. The vertical type is more commonly used and the horizontal type is only used in the high water table region. Its capacity is 1–10 m^3. Though the description of the various components mentioned under this section are common to both the types of KVIC models (vertical and horizontal types), some of the details mentioned pertain to vertical type only. In the KVIC model, the gas is stored in a tank. The tank is floating in slurry. The tank goes up as the gas gets generated and it lowers when the gas is consumed. The size of the tank depends on the size of the feed. Normally it is 50 times the amount of feed available per day. Generally, the tank is made of iron sheets, therefore, the cost of the biogas goes up. Recently, many organizations have started using PVC tanks.

Foundation is a compact base made of a mixture of CC and brick ballast. The foundation is a well-compacted using wooden ram and then the top surface is cemented to prevent any percolation and seepage. Digester (Fermentation Chamber) is a cylindrical shaped well-like structure, constructed using the foundation as its base. The digester is made of bricks and cement mortar and its inside

[17] http://arizonaenergy.org/Analysis/FossilFuels/Biogas.htm.

[18] http://oer.nios.ac.in/wiki/index.php/Biogas_Plant.

walls are plastered with a mixture of cement and sand. The digester walls can also be made of stone blocks in places where they are easily available and cheap instead of bricks. All the vertical types of KVIC Model of 4 M^3 capacity and above have a partition wall inside the digester. The biogas holder drum of the KVIC model is normally made of mild steel sheets. The biogas holder rests on a ledge constructed inside the walls of the digester well. If the KVIC model is made with a water jacket on top of the digester wall, no ledge is made and the drum of the biogas holder is placed inside the water jacket. The biogas holder is also fabricated out of FRP, high-density polyethylene (HDP) or ferroconcrete (FRC). The biogas holder floats up and down on a guide pipe situated in the center of the digester. The biogas holder has a rotary movement that helps in breaking the scum-mat formed on the top surface of the slurry. The weight of the biogas holder is 8–10 kg/m^2 so that it can store biogas at a constant pressure of 8–10 cm of water column. The inlet pipe is made of CC or Asbestos Cement Concrete (ACC) or Pipe. One end of the inlet pipe is connected to the mixing tank and the other end goes inside the digester on the inlet side of the partition wall and rests on a support made of bricks of about 1 feet height. The outlet pipe is made of CC or ACC or Pipe. One end of the outlet pipe is connected to the outlet tank and the other end goes inside the digester, on the outlet side of the partition wall and rests on a support made of bricks of about 1 feet height. In the case of KVIC model of 3 M^3 capacities and below (Fig. 13), there is no partition wall, hence the outlet pipe is made of short and horizontal, which rest fully immersed in slurry at the top surface of the digester. The biogas outlet pipe is fixed on the top middle portion of the biogas holder, which is made of a small GI pipe fitted with a socket and a gate valve. The biogas generated in the plant and stored in the biogas holder is taken through the gas outlet pipe via pipeline to the place of utilization.[19]

Advantages:

I. Floating-drum plants are easy to understand and operate.
II. They provide gas at a constant pressure, and the stored gas-volume is immediately recognizable by the position of the drum.
III. Gas-tightness is no problem, provided the gas holder is de-rusted and painted regularly.

Disadvantages:

I. The steel drum is relatively expensive and maintenance-intensive.
II. Removing rust and painting has to be carried out regularly.
III. The lifetime of the drum is short (up to 15 years; in tropical coastal regions about 5 years).
IV. If fibrous substrates are used, the gas-holder shows a tendency to get “stuck” in the resultant floating scum.[20]

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[19] http://arizonaenergy.org/Analysis/FossilFuels/Biogas.htm.

[20] http://www.appropedia.org/Floating_drum_biogas_digestor.

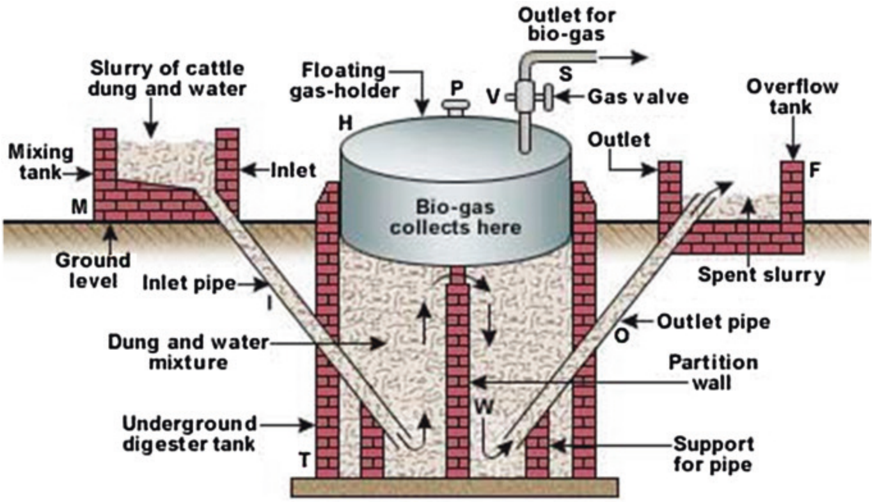

Fig. 13 KVIC floating-drum plant biogas digester (see footnote 19)

4.3 Deenbandhu Fixed-Dome Plant

The Deenbandhu Model is a semi-continuous-fed fixed-dome biogas plant. While designing the Deenbandhu model, attempt has been made to minimize the surface area of the BGP with a view to reduce the installation cost, without compromising on the efficiency. The design essentially consists of segments of two spheres of different diameters joined at their bases. The structure thus formed comprises of (i) the digester (fermentation chamber), (ii) the GSC, and (iii) the empty space just above the GSC. The higher compressive strength of the brick masonry and concrete makes it preferable to go in for a structure that could be always kept under compression. A spherical structure loaded from the convex side will be under compression and therefore, the internal load will not have any effect on the structure.

The digester of the Deenbandhu BGP (Fig. 14) is connected with the inlet pipe and the outlet tank. The upper part (above the normal slurry level) of the outlet tank is designed to accommodate the slurry to be displaced out of the digester (actually from the GSC) with the generation and accumulation of biogas and known as the ODC. The inlet pipe of the Deenbandhu BGP replaces the inlet chamber of Janta Plant.[21]

[21]http://arizonaenergy.org/Analysis/FossilFuels/Biogas.htm.

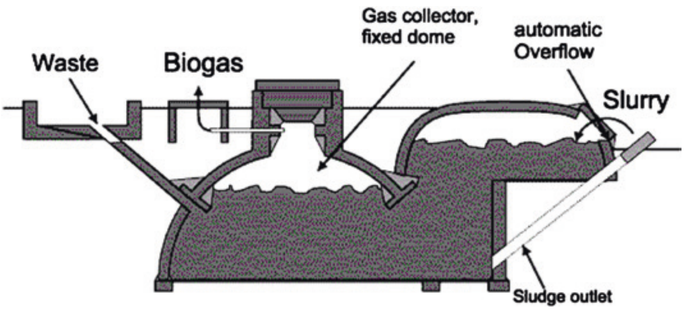

Fig. 14 Deenbandhu fixed-dome plant biogas digester (https://energypedia.info/images/d/df/Camartecfixdome.gif)

Advantages:

I. Capital investment for corresponding size of the plant is less.
II. As there are no moving parts.
III. Steel gas holder is not required.
IV. Life of the plant is expected to be comparatively more.
V. As the unit is underground, the space above the plant can be used for other purposes.
VI. Effect of low temperature is less.

Disadvantages:

I. The maintenance cost is high.
II. Construction of a dome portion of the unit is a skilled job and only trained mason can do it.
III. Requires more excavation work.
IV. Location of defects in the dome and their repair is difficult.
V. Release of gas is at variable pressure and it may cause a reduction in efficiency of gas appliances.
VI. It could be easily modified and adopted for use of other types of organic wastes.[22]

5 Worldwide Status of Biogas Production

Biogas usage is gaining increasing attention worldwide. It is about to become a popular energy source and is being utilized more in the United States. In 2003, the United States consumed 147 trillion BTU of energy from "landfill gas"; about 0.6 % of the total U.S. natural gas consumption.[23] Methane biogas has

[22]http://arizonaenergy.org/Analysis/FossilFuels/Biogas.htm.

[23]http://en.wikipedia.org/wiki/Biogas.

been tested to show that it can reduce 99 million metric tons of greenhouse gas emissions or about 4 % of the greenhouse gases produced by the United States (Cuellar and Webber 2008). In 2010, the total installed electrical capacity of these power plants was 2291 MW. The electricity supply was approximately 12.8 TWh, which is 12.6 % of the total generated renewable electricity (Bavutti et al. 2014). Nearly 62,000 biogas plants have been established through SNV-supported country programs in 2010, which is an increase of 18 % compared to 2009. The East African nations such as Tanzania, Kenya, Uganda and Ethiopia have also made good progress. Progress in West Africa has been restricted so far. The program has been initiated in Burkina Faso and Senegal as recently as 2011. The target for 1000 biogas plants by 2010 was achieved in Indonesia, Rwanda, and Tanzania. Cambodia surpassed 10,000 units and Vietnam even crossed 100,000. Up till now, 360,000 biogas digester plants have been installed through SNV-supported programs. But these figures are much lower compared to the achievements in the leading biogas nations like China and India. In 2010, China installed another 4.9 million units arriving at a total of 40 million operational plants. India constructed almost 120,000 units within the fiscal year 2009–2010 under the National Biogas and Manure Management Programme (NBMMP), making its total 4.25 million biogas plants in March 2010 (SNV Domestic Biogas 2011).

Upgrading of biogas has gained increased attention due to rising oil and natural gas prices and increasing targets for renewable fuel quotes in many countries. New plants are continually being built. The number of upgrading plants was around 100 in 2009 (Fig. 15).

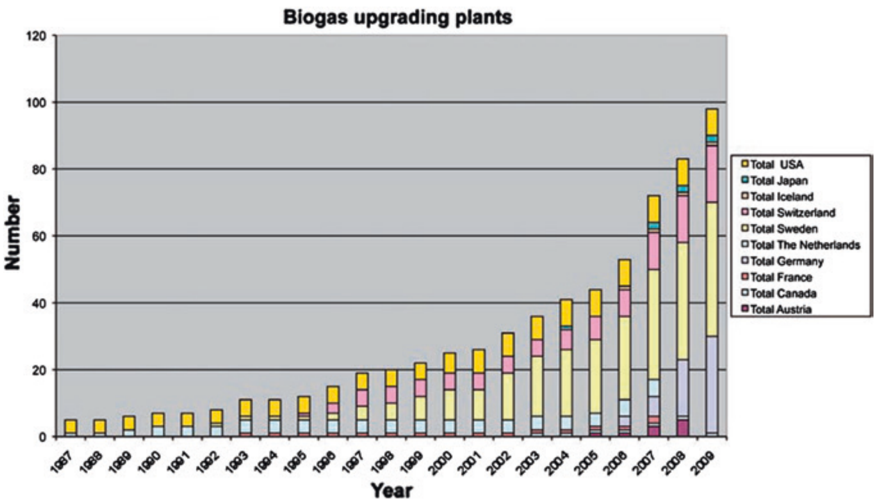

Fig. 15 Total number of upgrading plants from 1987 to 2009 (Pitersson and Wellinger 2009)

5.1 United States (U.S)

The United States has realized the various benefits of biogas. It has become a popular source of energy and is starting to be used more in the United States. In 2003, the United States consumed 147 trillion BTU of energy from “landfill gas”, about 0.6 % of the total U.S. natural gas consumption. Methane biogas derived from cow manure is being tested in the U.S. According to a 2008 study, collected by the Science and Children magazine, methane biogas from cow manure would be sufficient to produce 100 billion kilowatt hours—enough to power millions of homes across America. Furthermore, methane biogas has been tested to prove that it can reduce 99 million metric tons of greenhouse gas emissions or about 4 % of the greenhouse gases produced by the United States (See footnote 24).

5.2 United Kingdom (U.K)

There are around 60 no sewage biogas plants in the UK. Most are on-farm, and some larger facilities exist off-farm, which take food and consumer wastes. On 5 October 2010, biogas was injected into the UK gas grid for the first time. Sewage from over 30,000 Oxfordshire homes is sent to Didcot sewage treatment works, where it is treated in an anaerobic digester to produce biogas, which is then cleaned to provide gas for approximately 200 homes (See footnote 24).

5.3 Germany

Germany is Europe’s largest producer of biogas and leads the market in biogas technology. In 2010 there were 5,905 biogas plants operating throughout the country; Lower Saxony, Bavaria, and the eastern federal states are the main regions. Most of these plants are employed as power plants. Usually, biogas plants are directly connected with a CHP which produces electric power by burning the bio-methane. The electrical power is then fed into the public power grid. In 2010, the total installed electrical capacity of these power plants was 2291 MW. The electricity supply was approximately 12.8 TWh, which is 12.6 % of the total generated renewable electricity. Biogas in Germany is primarily extracted by the co-fermentation of energy crops (called ‘NawaRo’, an abbreviation of ‘Nachwachsende Rohstoffe’, which is German for renewable resources) mixed with manure. Due to guaranteed feed-in tariffs for “green” electricity under the Renewable Energy Sources Act (EEG) of 2001 and its amended versions of 2004, 2009, and 2012, the number of biogas plants has grown rapidly and reached 5,905 in 2010, with an installed electrical capacity of 2291 MW. According to certain predictions, the number of biogas plants in Germany will increase approximately to 7521, with an installed electrical capacity of 3185 MW by the end of 2012 (Naegele et al. 2012). The share of biogas in electricity supplied from renewable energy sources reached 14.4 % in 2011. The first challenge to be noticed is the high area-consuming of the biogas electric power supply. In 2011, energy crops for biogas production consumed an area of circa 800,000 ha in Germany. This high demand of agricultural areas generates new competitions with the food industries that did not exist yet. Moreover, new industries and markets were created in predominately rural regions entailing different new players with an economic, political and civil background. Their influence and acting has to be governed to gain all advantages this new source of energy is offering. Finally, biogas will furthermore play an important role in the German renewable energy supply if good governance is focused (See footnote 24).

5.4 China

In China, after 1975, slogans such as "biogas for every household" led to the construction of 1.6 million digesters per year, mainly being concrete fixed-dome digesters, which were cheap but of low quality. Up to 1982, more than seven million digesters were installed in China. In 1980, more than 50 % of all digesters were not in use. The consequence was that in 1979, construction activity slowed to less than one third of the previous one. This is equivalent to a targeted number of 80 million units by 2020.[24] It was reported there were about five million family sized plants operating in China in 1992, many of them redesigned to avoid leaking. According to some figures, only about three million digesters were in operation in 1991. This was because they were so crudely built and lack of well-trained personnel needed to fix them. These weaknesses have been the consequences of the concrete digester construction. Attention has recently been paid to combine quantity with the quality of plants and to match the technology with local conditions. Climatic as well as social and cultural conditions are being studied first before digesters are introduced. The rapid development of biogas in China received strong government support and sometimes, subsidies from local government and village government were up to 75 %. The biggest constraint in the biogas programs has been the price of the digesters. It was also learned that the popularization of biogas would only be successful when the direct benefits to the farmers were obvious. In 2009 about 34,000 small-scale biogas plants and 22,900 medium and large-scale biogas plants (MLBGPs, Fermenter > 50 m^3), with 3717 large-scale installations (Fermenter > 300 m^3) were included (See footnote 25). The increase in the number of biogas plants installed in China in the years 2004, 2005, 2006, 2007, 2008 was respectively 15.4, 18, 22, 26.5, 30.5 million. The biogas project of China is projected to increase to 10,000 livestock farms and 6000 industrial plants by 2020.[25]

[24] http://www.biogaschina.org/index.php?option=com_flexicontent&view=category&cid=18&Itemid=35&lang=en.

[25] http://www.ecotippingpoints.org/our-stories/indepth/china-biogas.html.

5.5 India

India had an extended and wide-ranging familiarity in the construction of simple and easy-to-operate biogas technologies to meet diverse climatic conditions and socioeconomic groups of users. Implementation of various management models of the sizeable biogas extension program had been developed and tried successfully. Central Government subsidies and campaigns for publicity have encouraged people to adopt biogas plants and make the biogas program very successful. The most common type used in India is the floating cover design digester which was introduced by the All-Indian Coordinated Biogas Program. This system is more expensive than the fixed-dome (Chinese) digester. India has placed far more emphasis on the survival of small-scale farmers than ensuring their efficiency and growth in a competitive environment through various policy instruments including biogas programs. The subsidies given to biogas programs have frozen the technologies, and created inefficient and fragile industries.[26] India has shown great development in biogas digester installation. The Indian Deenbandhu model of Floating-Drum type biogas digester has been a huge success throughout the world. In 1999, there were over three million family-sized biogas plants in India and by the end of 2007, the Indian Government provided subsidy for the construction of nearly four million family sized biogas plants (Bond and Templeton 2011). The numbers of biogas plants installed in India in the financial years 2007–08, 2008–09, 2009–10 and 2010–11 were 88,840, 107,929, 119,914, and 71,165 respectively.[27]

5.6 Mexico

In Mexico, Nestlé collects fresh milk in several dairy production areas where biogas digesters have been built to capture methane from cow manure and use it as energy. Additional biogas plants are under construction as a result of the sustainability analysis at the farm level (RISE assessment). In 2011, we project that around 35 % of the milk supplied for Nestlé in Mexico will come from dairy farms with biogas plants.[28]

5.7 Europe

Development of biogas technology shows a marked variation in Europe. Countries such as Germany, Austria, and Sweden are fairly highly developed in their use of

[26] http://www.mekarn.org/procbiod/an.htm.

[27] http://mnre.gov.in/schemes/decentralized-systems/schems-2/.

[28] http://www.dairy-sustainability-initiative.org/Public/CaseStudy.php?ID=472.

biogas. But there is a lot of prospective for biogas energy source in the rest of the continent, mainly in Eastern Europe. The major reasons behind this unexploited potential are due to different legal frameworks, education schemes, and the availability of technology. Also, negative public perception is another reason for slow growth (Energy technology developments 2013). The EU project "Sustainable and Innovative European Biogas Environment" (SEBE) was started after the gas crisis of Europe during December of 2008. It is financed by the CENTRAL program. The main aim is to deal with the energy dependence of Europe by establishing an online platform to combine knowledge and launch pilot projects aimed at raising awareness among the public and developing new biogas technologies. In February 2009, the European Biogas Association (EBA) was founded in Brussels as a non-profit organization to promote the deployment of sustainable biogas production and use in Europe. EBA's strategy defines three priorities: establish biogas as an important part of Europe's energy mix, promote source separation of household waste to increase the gas potential, and support the production of bio-methane gas vehicle fuel. In July 2013, it had 60 members from 24 countries across Europe (See footnote 24).

5.8 Australia

With feedstock from any organic waste, biogas technology can be deployed. But in Australia, the major area of potential utilization is within the agriculture sector. The industry accounts for 16.3 % of national inventory emissions in 2007. Methane recovery from animal waste is presently not largely practiced in Australia, primarily due to the large capital costs involvement. At feedlots, solid cattle manure is normally composted in open air facilities, and sold as fertilizer. Waste from pig and dairy farms is usually kept in the lagoon. Presently, the development of biogas sector in Australia is still in the nascent stage. In spite of the widespread applications of biogas technology worldwide, Australia has a very limited record of biogas projects. Because the agricultural sector accounts for a significant share of national emission, there is significant potential for biogas plants. In Australia, while there is no sign of the potential of biogas to CNG, past examples show that electricity generation from biogas is commercially viable (Doan 2009).

5.9 South Africa

With regard to using biogas for energy, South Africa lags behind the rest of the developed and developing world. In South Africa, there are nearly 200 small-scale biogas digesters, mostly developed by NGOs. Eskom's announced in July 2012 that its rebate program would extend to small-scale renewable projects. It became more feasible for companies than ever before to advance in the renewable energy sector in South Africa. Besides Eskom's rebate program, biogas investors could also approach the DTI (Department of Trade and Industry) for grant funding through their manufacturing incentive scheme (MCEP).[29]

5.10 Bangladesh

Grameen Shakti is one of the most prominent NGOs in the field of biogas having constructed 13,500 biogas plants. The Seed Bangla Foundation had proposed a 25 KW biogas-based power plant in Rajshahi. IDCOL, a government owned investment company had set up a target to establish 37,669 biogas plants in Bangladesh by 2012, under its National Domestic Biogas and Manure Programs (NDBMP). Target has also been set of 25 % of the total number of biogas plants in the northern region, which are yet to be brought under the national gas grid. Besides working in partnership with IDCOL, some organizations have established domestic biogas plants with their own money. These are Grameen Shakti (3664 plants), BRAC (3664 plants of their own), and some other private organizations which promote biogas plants independently. Moreover, since May 2011, IDCOL along with its partner organizations has constructed 18,713 biogas plants in different parts of Bangladesh (Rahman et al. 2013).

6 Environmental Considerations

6.1 Sustainability

Biomass energy production involves annual periodic removals of crops, residues, trees, or other resources from the land. These harvests and removals need to be at levels that are sustainable, i.e., ensure that current use does not deplete the land's ability to meet future needs, and also be done in ways that do not degrade other important indicators of sustainability. Because biomass markets may involve additional removals of residues, crops, trees, we should be careful to minimize impacts from whatever additional demand biomass growth makes on the land. As a result of established science and policy, farmers generally leave a certain percentage of crop residues on fields, depending on soil and slope, to reduce erosion and maintain fertility. Existing best management practices (BMPs) were developed to address forest management issues, especially water quality, related to traditional sawlog and pulpwood markets, with predictable harvest levels. But the development of new biomass markets will entail larger biomass removals from forests, especially forestry residues and small diameter trees. Sustainability standards

[29]http://www.engineeringnews.co.za/article/company-announcement-the-time-is-ripe-for-biogas-investment-says-sabia-ahead-of-launch-at-africa-energy-indaba-2013-01-31.

should ensure nutrients removed in a biomass harvest are replenished and that removals do not damage long-term productivity, especially on sensitive soils. Coarse woody material that could be removed for biomass energy also provides crucial wildlife habitat; depending on a state's wildlife, standards might protect snags, den trees, and large downed woody material. Biodiversity can be fostered through sustainability standards that encourage retention of existing native ecosystems and forest restoration. Lastly, sustainability standards should provide for regrowth of the forest—surely a requirement for woody biomass to be truly renewable.[30]

6.2 Air Quality

Especially with the emissions from combustion systems, biomass can impact air quality. Emissions vary depending on the biomass resource, the conversion technology, and the pollution controls installed at the plant. Because most biomass resources and natural gas contain far less sulfur and mercury than coal, biomass and natural gas power plants typically emit far less of these pollutants than do coal-fired power plants. Sulfur emissions are a key cause of smog and acid rain. Mercury is a known neurotoxin (See footnote 31).

6.3 Carbon Emissions and Control

Some of the environmental considerations and other concerns about the widespread implementation of bio-energy with carbon capture and storage (BECCS) are similar to those of Carbon Capture and Storage (CCS). However, much of the critique toward CCS is that it may strengthen the dependency on depleting fossil fuels and environmentally invasive coal mining. This is not the case with BECCS, as it relies on renewable biomass. There are, however, other considerations which involve BECCS and these concerns are related to the possible increased use of biofuels. Biomass production is subject to a range of sustainability constraints, such as: scarcity of arable land and fresh water, loss of biodiversity, competition with food production, deforestation, and scarcity of phosphorus. It is important to make sure that biomass is used in a way that maximizes both energy and climate benefits. There has been criticism to some suggested BECCS deployment scenarios, where there would be heavy reliance on increased biomass input.[31] Burning or gasifying biomass does emit carbon into the atmosphere. With heightened interest in renewable energy and climate change, scientists have put biomass carbon

[30] http://www.ucsusa.org/clean_energy/our-energy-choices/renewable-energy/how-biomass-energy-works.html.

[31] http://en.wikipedia.org/wiki/Bio-energy_with_carbon_capture_and_storage.

emissions under additional scrutiny, and are making important distinctions between biomass resources that are beneficial in reducing net carbon emissions and biomass resources that would increase net emissions (See footnote 31).

There is however presently no need to expand the use of biofuels in energy or industrial applications to allow for BECCS deployment. Today, there are already considerable emissions from point sources of biomass derived CO_2, which could be utilized for BECCS. Though, due to possible future bio-energy system upscaling scenarios, this may be an important consideration. The BECCS process allows CO_2 to be collected and stored directly from the atmosphere, rather than from a fossil source. This implies that any eventual emissions from storage may be recollected and restored simply by reiterating the BECCS process. This is not possible with CCS alone, as CO_2 emitted to the atmosphere cannot be restored by burning more fossil fuel with CCS (See footnote 32).

6.4 Conclusion

Renewable sources of energy have become indispensable for growth to meet the energy demands of any country and of the world in general. It is the same scenario in India. India is one of the leading countries in the field of renewable energy. It is fifth in the world in terms of installed wind capacity; it has developed a large amount of energy from solar. India had also taken interest in other types of renewable energy sources like biomass energy, wave energy, small hydro, geothermal, etc. As of December 27, 2012 in India 12.45 % of total energy was produced from renewable energy sources. In the electricity sector, India is the fifth largest in the world, having 210.936 GW of installed capacity as of 2012. Yet, per capita energy consumption of India is as low as 778 kWh. To increase energy consumption, India needs to look more into renewable sources.

India has huge potential for generating biomass energy. Biomass energy can be used to a great degree, especially in rural areas. The major need for energy in rural India is for cooking where people mainly use virgin wood. This creates a lot of pollution due to smoke and is a major health issue. Hygiene is also a major issue for rural India.

Biogas digester plants provide a sustainable way to meet concerns related to hygiene and also to meet the energy requirements in rural areas. Raw materials for the operation of biogas digester plant are found aplenty in villages, mainly cattle waste. Many biogas digester plants have already been set up in villages all across India, but the technology has not yet reached most parts because of the lack of initiatives and education. The installation cost of a biogas digester plant is also very high which is another deterrent for larger scale setup of plants. The government has many policies for biogas digester plants, which have been already discussed. But there needs to be proper awareness among people. This presents a challenge for the government.

Another thing that needs to be taken care of is reduction of cost. Typically, a biogas plant of around 1 m^3 costs about US$444 or about INR 20,000 to install. This needs to be reduced by better technology. Newer technology like implementation of plastic tanks as digesters can reduce the cost greatly, but this technology is still at the research stage. More subsidies need to be given and more initiatives need to be taken by the government.

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