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A Review On Biogas: Sustainable Energy Source For India

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Abstract: Biogas is one of the promising renewable technologies which can have ability to convert animal, agriculture, municipal and industrial waste into a non-polluting form of energy. Biogas is a mixture of gases (mainly methane, CO_2, traces of H_2S, moisture, etc.) produced through the anaerobic digestion of biodegradable organic matter. The digested slurry produces in biogas plants as a byproduct is a better source of of nutrient enriched organic matter for use in agriculture. In India, the biogas development programme was started in 1981 and was one of the approaches to reduce the energy crisis in rural areas. At the national level the estimated potential of biogas power generation up to 2020 by off-grid project was only 7.34 MWe (Megawatt electrical). The highest potential of biogas generation is done by Tamil Nadu i.e., 1.97 MWe followed by Karnataka i.e., 1.57 MWe. Under the National Biogas and Manure Management Programme (NBMMP) total 50,56139 number of biogas plants were installed from 1981-82 to 2020-21 out of which Maharashtra state has the highest no. of biogas plants i.e., 9,24111 followed by Andhra Pradesh (5,58962), Karnataka (5,10916), Uttar Pradesh (4,40930) and Gujrat (4,35272). Recently, the government has emphasized several initiatives, including GOBAR-DHAN, New National Biogas and Organic Manure, Sustainable Alternative towards Affordable Transportation, and the waste-to-energy program. These initiatives aim to enhance the utilization of waste, promote cleanliness in villages and towns, and support the Swachh Bharat Mission and Atmanirbhar Bharat campaign.

Keywords: Biogas, anaerobic digestion, Manure, Compressed biogas, GOARDHAN,

Introduction: Energy is a fundamental requirement for man's comfort and basic needs of everyday life. A vast majority of countries especially developing countries have energy crises with over reliance on fossil fuels. The national energy drivers of all countries globally are energy security, environmental protection, and economic growth. It is predicted that fossil fuel sources like coal, gas, and oil are headed for depletion within the next 10 decades, hence the need for alternative sources of energy. Additionally, international treaties like Agenda 21 and Kyoto Protocol advocate for a transition to renewable and low carbon sources of energy due to high greenhouse gas emissions associated with fossil fuels and the related climate change caused [1,2]. Biogas has proved to have significant potential as a renewable energy source for industrial as well as domestic applications and an efficient solution to the global energy crisis. Biogas also known as Gobar gas is competitive, viable, and generally a sustainable energy resource due to abundant supply of cheap feedstocks and availability of a wide range of biogas applications in heating, power generation, fuel, and raw materials for further processing and production of sustainable chemicals including hydrogen, and carbon dioxide and biofuels [3,4]. The capacity of biogas based power has been growing rapidly for the past decade with global biogas based electricity generation capacity increasing from 65 GW in 2010 to 120 GW in 2019 representing a 90% growth [5]. Biogas can be used directly for cooking and lighting as well as for power generation. Upgraded biogas/biomethane which can also be used to process methanol fuel. Compressed biogas (CBG) and liquid biogas (LBG) can be reversibly made from biomethane for various direct and indirect applications as fuels for transport and power generation. Biogas can be used in processes like combined heat and power generation from biogas (CHP), trigeneration, and compression to Bio-CNG and bio-LPG for cleaned biogas/biomethane. Fuels are manufactured from biogas by cleaning, and purification before reforming to syngas, and partial oxidation to produce methanol which can be used to make gasoline [6,7].

Biogas: The byproducts of anaerobic digestion of organic materials are commonly referred to as 'biogas' because of the biological nature of gas production. Biogas technology refers to the production of a combustible gas (called biogas) and a value added fertilizer (called slurry or sludge) by the anaerobic fermentation of organic material under certain controlled conditions. Biogas is produced by microbial activities and can be used only at the place where it is produced [8]. The main constituents of biogas are**:**

- Methane 55-65%
- Carbon Dioxide 35-45%
- Trace component (Hydrogen, Moisture, Hydrogen Sulphide, Ammonia, Non Methane Volatile organic, etc.).

Biogas, in its raw form, that is without any purification, can be used as clean cooking fuel like LPG, lighting, motive power and generation of electricity. It can be used in diesel engines to substitute diesel up to 80% and up to 100% replacement of diesel by using 100% Biogas Engines. Further, Biogas can be purified and upgraded up to 98% purity of methane content to make it suitable to be used as a green and clean fuel for transportation or filling in cylinders at high pressure of 250 bar or so and called as Compressed Bio-Gas (CBG). The comparative value of energy and their efficiencies of differentfuels are given in Table.1 [9]

Commonly Used Fuels	Calorific Values	Thermal Efficiency
Bio-gas	4000-5000 KCal/m^3	55%-60%
Dung cake	1900-21003 KCal/Kg	5%-11%
Firewood	2100-4300 KCal/Kg	15-20%
Diesel (HSD)	10550 KCal/Kg	60-70%
Kerosene	10850 KCal/Kg	50-55%

T**able.1** The Calorific Value and Efficiency

Method for preparation of biogas: The different pathways of bio-methanation process are suggested by several investigators. Macro level energy conversion of organic waste in bio-methanation is shown. In this process of conversion of energy from organic mass is mainly utilized in cell synthesis and formation of methane and carbon dioxide besides some part of it remains in the effluent [10]. A simple flow chart may describe the three step process of bio- methanation as shown. These are briefly described below:

Hydrolysis: Hydrolysis is the first step in anaerobic degradation and also the rate limiting step. The hydrolysis of organic polymers such as polysaccharides, fats and proteins converts these polymers into smaller units, such as sugars, long-chain fatty acids and amino acids. This group of bacteria called as facultative anaerobes/microbes.

Acitogenesis: The sugars, long-chain fatty acids and amino acids resulting from hydrolysis are used as substrates by a wide variety of bacterial generation of different fermentative organisms or by anaerobic oxidizers. The complex organic matters in liquid phase digestion convert the small water-soluble molecules by fermentation into acetate,carbon dioxide and hydrogen. The acid forming bacteria also convertsthe intermediate products to acetic acid, carbon dioxide and hydrogen.

Methanogenesis: Acetate, carbon dioxide and molecular hydrogen can be directly utilized as a substrate by the group of anaerobic microorganisms called Methane genesis or methane forming bacteria. Methane can be synthesized via two different pathways, of which one involves acetateand the other molecular hydrogen. The estimations indicated that about 70% of the methane is produced from acetate and 30% comes from hydrogen. The Volatile Fatty acids (VFA) accumulation is to be avoided in the digester to produce the high gas content.

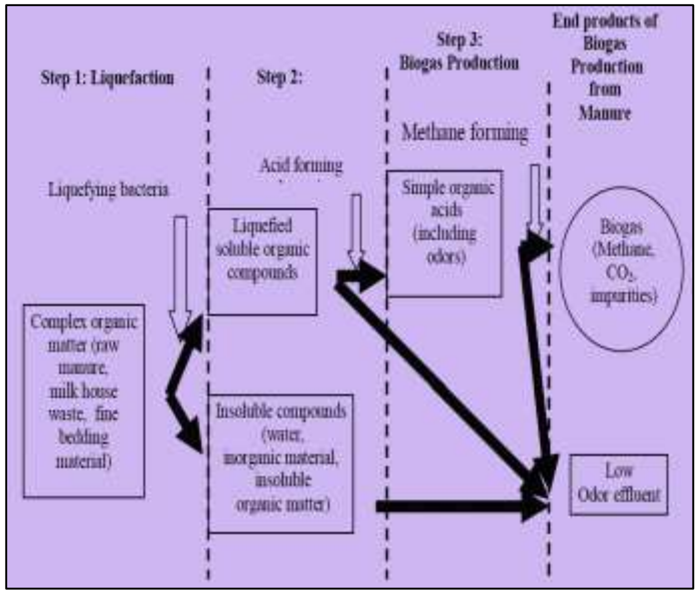

Figure: 1 Three Stage Process of Bio methanation

Stoichiometric Calculation of the Biogas Yield and Composition

Bio-methanation process is carried out by symbiotic action of methane and acid producing bacteria. The interrelated behaviors of all classes of bacteria create the environment for each other to survive and grow simultaneously. The estimation of biogas production form the organic waste materials may be done on the basis of Stoichiometric equation of the conversion process. The simple equation is considered by Ghaly and Ramkumar [11]for calculations of the theoretical yield of methane and carbon dioxide, i.e. biogas, produced by anaerobic digestion using the Boswell's formula [12]

$$C_n H_a O_b + (4n - a - 2b) H_2O \rightarrow (4n + a - 2b)/8\, CH_4 + (4n - a + 2b)/8\, CO_2$$

Veziroglu, [13] has given the formula for the biogas productionfrom organic substances which are not containing sulfur materials and can be written as:

$$C_aH_bO_cN_d + (4a - b - 2c + 3d)/4\, H_2O \rightarrow (4^a + b - 2c - 3d)/8\, CH_4$$
$$+ (4a-b+2c+3d)/8\, CO_2 + d\, NH_3$$

The formula for the conversion of organic substance in an aqueous environment into CH_4 and CO_2 and into ammonia and hydrogen sulphide, (if N and S are contained in the substrates) is given by Boyle [14].

$$C_nH_aO_bN_cS_d + (4n - a - 2b + 3c + 2d)/8\, H_2O \rightarrow$$
$$(4n - a + 2b + 3c + 2d)/8\, CO_2 + (4n + a - 2b - 3c - 2d)/8\, CH_4$$
$$+ cNH_3 + d\, H_2S$$

It is interesting to note that any organic matter will generate biogas,but the higher the energy of the materials, the more biogas they will create. For example, deep fryer oil can generate about 60 times as much biogas as cow dung for any given quantity.

Factors affecting the biogas production: All kinds of organic waste such as kitchen waste and garden waste, cattle dung and sewage, etc. can be used in a biogas plant. The efficiency of the biogas production is affected by the following factors [15,16]:

Organic Loading Rate (OLR): The organic loading rate (OLR) of a process is a measure of how much organic material is fed to each cubic meter of reactor volume during one day (i.e. Kg of VS/m^3 or COD/m^3 day).The biogas is formed from the anaerobic degradation of volatile solids (VS). The volatile solids fed per Kg in reactor will normally produces maximum biogas in the range of 0.25-0.70 m^3 depending on the operating conditions of reactor. Accordingly, the loading rate should be in the range of 1-1.5 Kg volatile solids/m^3 digester/day which is highly dependent on the reactor design. The biogas production is also affected by overfeeding or underfeeding of the feed materials. In continues feed digesters, the large fluctuations of flow and concentration of substrate will also give low biogas production. Volatile Solids (VS) is measured as the weightof solids that is combustible "volatilized" at a temperature of 550°C.It is reported as a percent of the total weight of the manure sample. Methane production is often based on the volatile solids portion of themanure. Approximately 50-70% of the VS can be converted to biogas depending on the design of the digesters.

pH-value: The pH affects severely the biogas and methane production rate which decreases with high and low pH values. The pH value should be between 7 and 7.4 and the dilution for water and fresh dung ratio 1:1 by weight. The maximum percentage of methane can be produced in the optimum range of pH vales 6.8-7.2. The methane forming bacteria cannot survive below 5.5 pH, while acid forming bacteria can survive up to 4.5 pH. Therefore, the water is normally used for buffering solution and to be used in sufficient quantities for anaerobic digestion/fermentation process. The control of decrease in pH of an anaerobic reactor may be done by stopping the feeding and increase the buffering capacity, e.g. through adding some chemicals as calcium carbonate, sodium bicarbonate or sodium hydroxide.

Temperature : The biogas production is highly dependent on operating temperature of anaerobic digester. Three ranges of temperatures and their respective retention times are given in Table 2 for the operationof digesters.

	Temperature Range	Retention Time	
➢	Psychrophilic	0 to 20°, 100-120 days	
➢	Mesophilic	20 to 42°C and	30- 60 days
➢	Thermophilic	42 to75°C	3- 20 days

Table.2 Temperature and Retention Time

Methanogenesis is also possible under psycrophilic conditions (temperatures below 20^{0}C) but occurs at lower rates. The quantity and quality of biogas production is different in different temperature ranges. Optimum gas production is also found at 33^{0}C and 52^{0}C in Mesophilic and Thermophilic ranges respectively. The trend in biogas production with temperature in different ranges is shown in Figure. The fluctuations in temperature in any range leads to inhibition of methane formation.

Carbon to Nitrogen Ratio: Microorganisms need both nitrogen and carbon for assimilation into their cell structures. The C/N ratio varies from a feedstock to another as shown in Table 3. It is mentioned as an important parameter, affecting the biogas production.

Feedstock	C/N ratio Range
Poultry litter waste	5-10
Grass clippings	12-25
Horse stable manure	25-27
Fruit waste	28-35
Leaves	30-80
Straw, wheat	100-138
Night soil	6-10
Sewage sludge	6-8
Animal manure (without litter)	11-25
Farmyard manure (average with litter)	14-20
Green vegetable wastes, weeds	11-20
Cereal straw	45-130
Potato peels	22-25
Cow dung	25-30
Poultry manure	8-15
Pig manure	18-20
Garbage	16-22

Table 3. C/N Ratios of different Types of Feedstock

Nutrients and Trace Elements: Microorganisms require the macro and micro nutrients as trace elements such as phosphorous, nitrogen, sulfur, calcium, potassium, iron, nickel, cobalt, zinc and copper. These are essential required for optimum activity of the microorganisms involved in anaerobic digestion. The most important nutrients are nitrogen and phosphorousand it has been suggested that the C: N: P ratio should be kept at a minimum of 100: 28: 6 [17].

Hydraulic Retention Time (HRT): Hydraulic retention time varies with operating temperatureof the anaerobic digester. It may be defined as the average time a volume element of the liquid medium resides inside the reactor. A better production of biogas found at an increase in HRT, if all other parameters kept constant. Anaerobic digestion can be performed with a relative short HRT,i.e. "high rate" systems, or with long HRT, i.e. "low rate" systems. Low rate systems are normally used to digest slurries and solid wastes,while high rate systems are usually used for treatment of wastewater.

Degree of Mixing: Mixing is a control process to keep uniform the pH and other environmental conditions of slurry in the digester. It distributes the buffering agents throughout the reactor volume and prevents localizedbuild up of high concentrations of intermediate metabolic products, which may inhibit methanogenic activities [18].

Toxicity: Methanogens are most sensitive to any kind of toxicity in comparison to other microorganisms in anaerobic degradation. The Table 4 lists the limit concentrations (mg/l) for various inhibitors[19]

Substance	[mg/l]
Copper	10-250
Calcium	8000
Sodium	8000
Magnesium	3000
Nickel	100-1000
Zink	350-1000
Sulphur	200

Table 4. Limiting Concentrations for various inhibitors of bio-methanation

Efficiency of Gas Production and Uses

The efficiency of Biogas production is measured in terms of yield as a fraction of the theoretical yields of gas. The biogas productionper Kg of raw material may be a good indicator for performance of digester. The efficiency of plant can also be measured on the basis of gas production per unit reduction in total solids, volatile solids, Chemical Oxygen Demand (COD) or Biological Oxygen Demand (BOD). The Total solids and volatile solids are normally used to measure the efficiency as biomass is solid material. The efficiency of the biogas production depends on the retention time (percentageof daily input of biomass related to total volume). Normally, the efficiency can be expected around 60%. The biogas production also depends on the Biological Oxygen Demand (BOD) in the wastewater.The BOD reduction will generate 0.8 m^3 of biogas each Kg of BOD removal. Adding water with low BOD from the end of the anaerobic process will dilute the high inlet BOD and improve the biogas process.

Uses for Biogas (methane)

The biogas may be used for variety of applications. Some of the application areas are:

(1) producing steam (i.e. heat)
(2) generating electricity (with power generators)
(3) producing "CNG"(with purifiers and compressors).

Major Benefits

The cooking in rural areas is still largely depending on the use of traditional cook stoves (Chullha's). They are burning dung cake, fire-wood and agricultural waste in addition to kerosene up to some extent. The installation of bio-gas plants would directly replace the useof above three and in saving them, following gains would be made [20]:

(a) Reduction in pollution due to burning of dung and other biomass materials. Dung can be conserved, if biogas plants are used. Again, the dung after digestion in gas plant preserves more of Nitrogen, Phosphorus and Potash. The slurry coming out after digestion from different capacity plants are given in Table 5

Size (m^3)	Slurry Manure (Tonnes/yr)
10	49275
15	73912
20	98550
25	123187
35	172462
45	221737
60	295650
85	418837

Table 5. Slurry manure from Biogas Plant

(b) The rural people would not be dependent on wood which is used for cooking. The deforestation and ecological imbalances can be reduced.

(c) In rural areas instead of kerosene the biogas can be used for lighting. This would reduce the dependence on fossil oil directly and in saving foreign exchange.

(d) The most important benefit would be in keeping the clean inhabitation and environment. The human beings can be saved form bacterial infections and other insects.

(e) The combustion of biogas produces carbon dioxide (CO_2), a greenhouse gas. The carbon in biogas comes from plant matter that fixed this carbon from atmospheric CO_2. Thus, biogas productionis carbon-neutral and does not add to greenhouse gas emissions. Further, any consumption of fossil fuels replaced by biogas will lower CO_2 emission.

Compressed Biogas

(i) Sustainable Alternative Towards Affordable Transportation (SATAT) was launched on 1st October 2018 aiming to establish an ecosystem for production of Compressed Bio Gas (CBG) from various waste/biomass sources in the country [21].

(ii) Under SATAT, Oil and Gas Marketing Companies IOCL, BPCL, HPCL, GAIL and IGL have invited Expression of interest (EoI) to procure CBG from potential entrepreneurs for further marketing.

(iii) A list of the recent initiatives taken be the Ministry to promote SATAT is as under:

- Oil & Gas marketing companies are executing long termagreements for off-take of CBG at an assured price.
- Bio manures produced from CBG plants has been includedas "Fermented Organic Manure" under Fertilizer Control Order 1985 vide gazette notification dated 13 July 2020.
- Reserve Bank of India has notified inclusion of CBG projects under Priority Sector Lending vide directives to Banks dated4.9.2020.
- State Bank of India has also developed a new loan product for financing of CBG projects.
- Ministry of New and Renewable Energy has extended Central Financial Assistance (CFA) Scheme for FY 2020-21.
- State Level Committees have been constituted forimplementation and monitoring of SATAT initiative in Statesof Haryana and Punjab
- MoPNG is also in discussion with Multilateral Financial Institutions like World Bank, Asian Development Bank (ADB)etc. for enabling financing options via line of credit for CBG developers.

(iv) Further Ministry is also engaged with:

- State Government to create enabling mechanism for establishing Bio mass supply chain to ensure sustainable supply of bio mass at a stable price for at least a period of 10 years.
- Ministry of Agriculture and Farmers Welfare to include Digested Bio Gas Slurry (DBGS) produced from CBG projects under FCO.
- Central Pollution Control Board to categorize CBG Projects under 'White Category'.
- Department of Fertilizer to extend benefits of Market Development Assistance in form of Rs. 1500/ton to FOM and direct fertilizer companies and marketing entities to co- market FOM with fertilizers.
- Department of Economic Affairs to facilitate creation of line of funding from multilateral financial institutions for CBG projects[22,23].

Asia's largest Compressed Bio Gas (CBG) plant in Punjab's Sangrur on 18th Oct 2022. It is spread across an area of 20 acres & has been commissioned with an FDI of approximately Rs. 220 crores

Gobardhan- (Galvanizing Organic Bio-Agro Resources Dhan) Waste to Wealth:

GOBARDHAN was launched by the Government of India in April 2018 as a part of the Solid and Liquid Waste Management componentunder Swachh Bharat Mission (Grameen) to positively impact village cleanliness and generate wealth and energy from cattle and organic waste. The main focus of GOBARDHAN is to keep villages clean, increase the income of rural households, and generate energy and organic manure from cattle waste. As rural India has already attained the Open Defecation Free (ODF) status, the importance of GOBARDHAN has increased as it supports the villages in achieving ODF-plus status, which is an important objective of Swachh Bharat Mission (Grameen) Phase II.

Presently, various Ministries/Departments are implementing schemes for the management of cattle and agricultural waste throughthe setting up of biogas plants. However, a unified approach would be beneficial to ensure convergence among various schemes and to get full benefits from them. Accordingly, GOBARDHAN: Waste to Wealth programme has been designed to provide a common platform for schemes of different Ministries/Departments [24].

Objectives of GOBARDHAN:

- To support villages effectively manage their cattle waste,agricultural waste/residue and all other organic waste.
- To support communities to convert their organic waste (especiallycattle dung) to wealth through generation of manure and energy out of waste.
- To promote environmental sanitation and curb vector-borne diseases through effective disposal of waste in rural areas.
- To create livelihood opportunities in rural areas and enhance the income of farmers and other rural people by supporting them to convert their waste to wealth.
- To promote rural entrepreneurship by involving entrepreneurs, SHGs and Youth Groups in the setting up and operation and management of biogas plants.

Advantages:

- Helps in managing a major portion of solid waste in villages i.e., cattle dung and agricultural waste and promotes environmental sanitation [25].
- Substantially reduces vector borne diseases and promotes public health.
- Promotes household income and saving as the use of biogasreduces the expenditure on LPG.
- Helps in generating organic manure which enhances agriculture and farm productivity.
- Promotes employment and income generation opportunities for SHGs/farmers groups.
- Helps in reducing greenhouse gas emission and promotes environmental sustainability.
- Helps to save foreign exchange by reducing the need for the import of natural gas.

Status of waste-to-energy plants and biogas production in different states of the regions:

At the National level the estimated potential of biogas power generation up to 2020 by off-grid project was only 7.34 MWe (Mega Watt Electrical). The highest potential of biogas generation is done by Tamil Nadu i.e., 1.97 MWe followed by Karnataka i.e., 1.57 MWe and states like Bihar, Chhattisgarh, Delhi has zero biogas power generation. In India, the rate of biogas dissemination in rural households is insignificant. Only about 40% biogas plants have been installed under the biogas development programme against the total potential of 12 million domestic biogas plants as estimated by MNRE (CSO, 2014). In addition, along with family type biogas plants, 400 biogas (off-grid) power plants have been set up with a power generation capacity of about 505 MW (MNRE,2015). Government of India has implemented National Biogas and Manure Management Program (NBMMP), which is an off-grid biogas power generation program along with waste to energy (MNRE, 2015). But still the dissemination of biogas technology is not satisfactory, the reason might be lack of awareness, lack of technical and informational barriers and non-availability of natural resources. India's capacity of waste to energy is about 254.73 MW and biogas power generation (off-grid) is about 7.34 MWe only [26].

States/UT	Waste to Energy (In MW)	Biomass Power + Bagasse Cogeneration (In MW)	Biomass Cogeneration (Non-bagasse) (In MW)	Biogas Power Generation (off-grid) Projects (In MWe)
Andhra Pradesh	40.82	378.20	98.98	0.47
Bihar	0.00	113.00	8.20	0.00
Chhattisgarh	0.33	228.00	2.50	0.00
Delhi	52.00	0.00	0.00	0.00
Gujarat	11.28	65.30	12.00	0.02
Haryana	4.00	121.40	84.26	0.14
Himachal Pradesh	0.00	0.00	7.20	0.00
Jharkhand	0.00	0.00	4.30	0.00
Karnataka	**7.80**	**1866.60**	**15.20**	**1.57**
Kerala	0.00	0.00	0.72	0.12
Madhya Pradesh	15.40	93.00	12.35	0.10
Maharashtra	**28.71**	**2499.70**	**16.40**	**0.83**
Meghalaya	0.00	0.00	13.80	0.00
Odisha	0.00	50.40	8.82	0.01
Punjab	14.92	194.00	123.10	0.92
Rajasthan	3.00	119.30	2.00	0.01
Tamil Nadu	**10.45**	**969.00**	**28.55**	**1.97**
Telangana	19.50	158.10	1.00	0.21
Uttar Pradesh	44.63	1957.50	158.01	0.76
Uttarakhand	1.89	73.00	57.50	0.07
West Bengal	0.00	300.00	19.92	0.06
India	**254.73**	**9186.50**	**674.81**	**7.34**

Table. 6. **Selected State-wise Bio-energy Projects Installed for Power Generation under Various Schemes/Programmes of Ministry of New and Renewable Energy (MNRE) in India as on 29.02.2020**

Under the National Biogas and Manure Management Programme (NBMMP), total 50,56159 number of biogas plants were installed from 1981-82 up to 2020 are shown in the following table out of which Maharashtra state have the highest number of biogas plants i.e., 924111 followed by Andhra Pradesh 5,58962, Karnataka 5,10916, Uttar Pradesh 4,40930 and Gujrat 4,35272. India biogas market size was valued at USD 1.40 billion in 2021. The market is expected to grow from USD 1.47 billion in 2022 to USD 2.25 Billion in 2029 at a Compound Annual Growth Rate of 6.3% in the 2022-2029 period [27].

States/UTs	No. of Biogas Plants
Andaman and Nicobar Islands	97
Andhra Pradesh	558962
Arunachal Pradesh	3609
Assam	138483
Bihar	129925
Chandigarh	169
Chhattisgarh	59850
Dadra and Nagar Haveli	681
Delhi	578
Goa	4226
Gujarat	435272
Haryana	63433
Himachal Pradesh	47706
Jammu and Kashmir	3200
Jharkhand	7823
Karnataka	510916
Kerala	153203
Madhya Pradesh	376558
Maharashtra	924111
Manipur	2128
Meghalaya	10659
Mizoram	5856
Nagaland	7953
Odisha	271809
Puducherry	17541
Punjab	185998
Rajasthan	72446
Sikkim	9044
Tamil Nadu	223894
Telangana	19702
Tripura	3710
Uttar Pradesh	440930
Uttarakhand	364582
West Bengal	1105
India	**5056159**

Table 7: State-wise Cumulative Number of Biogas Plants under National Bio-gas and Manure Management Programme (NBMMP) in India (1981-1982 to 2020-2021 upto 30.06.2020)

Conclusions: Biogas is competitive, viable, and generally a sustainable energy resource due to abundant supply of cheap feedstocks and availability of a wide range of biogas applications in heating, power generation, fuel, and raw materials for further processing and production of sustainable chemicals including hydrogen, and carbon dioxide and biofuels. The capacity of biogas based power has been growing rapidly for the past decade with global biogas based electricity generation capacity increasing from 65 GW in 2010 to 120 GW in 2019 representing a 90% growth. India biogas market size was valued at USD 1.40 billion in 2021. The market is expected to grow from USD 1.47 billion in 2022 to USD 2.25 Billion in 2029 at a Compound Annual Growth Rate of 6.3% in the 2022-2029 period. Biogas use helps keep the environment clean by preventing harmful environmental and health impact from the huge agricultural wastes available globally. Therefore, biogas provides financial, economic, environmental, and health benefits for the critical mass of humanity who rely on agriculture for subsistence as well as cash. On social energy sustainability, planned investment in biogas plants utilizing agricultural wastes will help in job creation and generation of extra income streams, hence reducing unemployment while improving the income and hence sustainability of smallholder agriculture and incorporate farmers in the transition to low carbon and green electricity and energy future while leaving a huge positive impact to the society.

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