

# Feasibility Study on Implementing Kitchen Waste-Based Biogas Plant at Tezpur University, Assam

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**Abstract** The growing demand for cooking fuel and non-reliable supply of commercial cooking fuel has become a major concern in recent years. In this context, biogas, a clean and renewable energy source, can be a supplement to non-renewable conventional cooking fuel. In India, small-sized biogas plants have been prevalent in domestic sectors with mixed degree of success. However, the application of community-sized biogas plants is very limited. In case of residential institute like Tezpur University, Assam, India, considering the huge amount of food waste generated, conversion of kitchen waste into useful cooking gas (biogas) through anaerobic digestion can be a better option to supplement the elevated requirement of LPG. In this work, feasibility study of renewable energy-based cooking system (biogas plant, size 50 m<sup>3</sup>), implemented in one of the hostels of Tezpur University, is thoroughly examined from commissioning to operational stage, in order to assess the barriers and carriers of such renewable energy technology. A study investigated the performance of the installed plant, feedstock characteristics, composition and economic assessment of biogas-fuelled cooking at Tezpur University campus. Performance analysis and economic assessment of the 50 m<sup>3</sup> biomethanation plant showed that it can be a viable option for utilization of the food waste generated in educational institutions through production of clean cooking fuel. However, proper monitoring of feeding rate and quality is critical for smooth performance of the biogas system.

**Keywords** Energy • Kitchen waste • Biogas • Digester

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## 1 Introduction

Sustainable supply of energy is one of the main challenges that mankind is facing, particularly because of imbalance between energy supply and demand and the need to tackle the rapid climate change. In this context, use of renewable energy sources is becoming increasingly essential. With the growing energy demands, due to depletion of fossil fuel resources and population explosion, the need for renewable energy source has drawn the attention for all sectors of development. The theoretical potential for renewable energy exceeds current and projected global energy demand by a large extend. However, the main challenge still remains: to capture and utilize a sizable share of that potential to provide the desired energy demand in a cost-effective and environmentally sound way (IPCC Report 2013).

One of the key technologies for the sustainable use of biomass-based renewable energy technology is biogas technology. Anaerobic digestion (AD) process that generates biogas has been considered as one of the appropriate waste-to-energy conversion technologies and is widely used in the treatment of different organic wastes (Ten Braummeler 1993), municipal solid waste, sewage sludge, food waste, animal manure, plant biomass, crop residues, energy crops, etc. The process of anaerobic digestion converts biodegradable organics into biogas which comprises methane (55–75%) and carbon dioxide (25–45%) with a calorific value of 20 MJ/m<sup>3</sup> (Myles 1987; Steffan et al. 2000). Biogas, a clean energy, is considered as the appropriate technology that meets the basic need for cooking fuel in rural India. So far, biogas production has been quite dominant at household and community levels rather than large scale in India. On the one hand, biogas remains the primary energy obtained, whereas, on the other hand, the digested slurry obtained from anaerobic digestion can be efficiently utilized as fertilizer for agricultural applications as it is superior in terms of its nutrient content and can be used as a soil conditioner and plant nutrient.

Considering the suitability of wide range of feedstock for anaerobic digestion, food waste could also be considered as a potential AD feedstock because of its biodegradable nature and abundance. Almost one third of the total food produced for human consumption each year is wasted accounting to about 1.3 billion tonnes as per the study of global food waste published in 2011 by The Food and Agriculture Organization of the UN. This major portion of food waste is mostly distributed in the developing countries like India (FAO 2011). The food waste mostly includes unconsumed food and food preparation leftovers. With growing concerns over waste disposal, increasing cost of energy supply, a judicious and scientific approach of conversion of food waste to energy has become an inevitable option. Anaerobic digestion of food waste has been an economically viable energy conversion route through production of biogas. Many factors related to feedstock characteristics, digester design and operation conditions affect the performance of anaerobic digestion processes (Hawkes 1980; Fischer et al. 1986). Therefore, physical and chemical characteristics of the organic waste are important for designing and operating anaerobic digesters. In general, characteristics of food wastes are highly variable

depending on their sources with a moisture content in the range of 74–90%, volatile solid to total solid ratio of 80–97% and carbon to nitrogen ratio of 14.7–36.4% (Zhang et al. 2007). Anaerobic digestion of considerable amount of food and vegetable waste can be a viable option with reference to educational institute for the production of biogas. Further, in case of residential institutions, cooking is one of the major energy-consuming sectors. With alarming concerns such as fuel price hike and LPG shortage, it has become difficult to meet the growing energy demand most of the time. Thus, in order to meet the cooking energy needs, biogas can be considered as a better alternative if it can be economically utilized as a clean source of energy. Keeping in view of the above discussion, this study was initiated to examine the feasibility of converting the food waste into biogas energy through a 50 m<sup>3</sup> community-sized biogas plant present in one of the hostels (*Patkai Men's Hostel*) of Tezpur University, Assam, India. The different activities involved since the commissioning to the operational stage of the project were examined in order to assess the barriers and carriers of such renewable energy technology. The study also investigated the performance of the installed plant, feedstock characteristics, composition and economic assessment of biogas-fuelled cooking at Tezpur University campus and was also carried out to examine the viability of the system.

## 2 Materials and Methods

### 2.1 *Background Data Collection and Monitoring of Construction and Operation of Biogas Plant (50 m<sup>3</sup>)*

Before commissioning of the plant, background information was collected from the hostels of Tezpur University in order to understand the cooking energy consumption. A questionnaire survey was carried out comprising questions on LPG usage, food waste generation, etc. From the date of construction to the date of commissioning, up-to-date details of the progress of work, material procurement, human labour engaged, etc. were properly recorded. The biogas plant was a Shakti Surabhi-type biogas digester developed for kitchen waste-based biogas production by Vivekananda Kendra – Natural Resources Development Project (VK-NARDEP), Kanyakumari, India.

### 2.2 *Feedstock Characteristics*

Following parameters of the food waste were determined, viz. total solid (TS), total suspended solid (TSS), ash, total organic carbon (TOC), total nitrogen (TN) and pH. The TS was determined according to the standard procedure (ASTM Test No. D-271-48). A total suspended solid (TSS) (amount of filterable solids in a sample) was measured by passing the sample through a glass fibre filter. Ash content of the

feedstock sample was measured with the standard procedure of ASTM Test No. D-271-48. The total organic carbon was determined using the TOC analyser (Liqui TOC II of make Elementer). The food sample was first grinded properly and then filtered using a filter bag of size 150 microns before analysis. The liquid sample that was obtained was tested for total organic carbon. Total inorganic carbon (TIC) and total carbon (TC) were also determined from the TOC analyser. The total nitrogen of the food sample was measured by the standard Kjeldahl method using the Kjeldahl apparatus. Volatile suspended solids (VSS) are the amount of volatile solids in a dried filtered sample. It is measured by igniting the dried filtered sample in a muffle furnace at 550 °C.

### ***2.3 Determination of Biogas Yield***

Biogas plant was fed with an amount of 85–90 kg of food waste daily. The biogas yield of the plant was measured at an interval of 24 h. The holder height was measured regularly by taking the difference of the height of the holder of the day with that of the previous day; the volume of the gas holder was measured which corresponds to the amount of biogas yield per day. In case of usage, the usage hours were noted, and correspondingly approximate amount of biogas used was calculated by considering the hourly fall of the holder height. Thus by considering the difference in height as well as the drop during usage, the amount of biogas formed was calculated in m<sup>3</sup>. The amount of biogas produced per kg of total solid was also calculated.

### ***2.4 Determination of Composition of Biogas***

Biogas composition was measured at different intervals regularly in terms of methane content. It was measured using a biogas analyser (Ambtronics Engineers Private. Ltd., Model No: MS panel 830213). The biogas analyser is equipped with IR 5000 infrared gas detector which is a microcontroller-based gas detector that continuously monitors the CH<sub>4</sub> and CO<sub>2</sub> in %V/V and H<sub>2</sub>S in ppm levels. For the present study, only methane content was recorded.

### ***2.5 Determination of Equivalent Amount of LPG***

For the determination of equivalent amount of LPG, a water boil test was done. An amount of 6 L of water was taken in a utensil and was allowed to boil using biogas until it reaches 100 °C. During the operation, the initial height, the final height of the holder and the time duration for its boiling were noted. The same was repeated by

using LPG and the initial and final weight of the LPG cylinder were noted. Thus, by comparing the volume of biogas to that of the amount of LPG, equivalent amount of LPG was calculated.

## 2.6 Economic Analysis of the Biogas Plant

The economic analysis of the 50 m<sup>3</sup> biogas plant was carried out by considering all the cost, i.e. capital cost, maintenance cost, electrical cost, etc., for a period of 10 years considering an increase of 4.5% price rise every year. The payback period was calculated by calculating the cumulative savings that could have been incurred in case of LPG. As per the number of LPG savings incurred during a month of experimentation and the prevailing price of LPG, the payback period was calculated. The payback period was computed as the smallest value of  $n$  that satisfies the Eq. 1. where  $B_n$  and  $C_n$  represent the benefits and costs, respectively, associated with the investment at each period of  $n$ .

$$\sum_{n=0}^{nsp} (B_n - C_n) \geq 0 \quad (1)$$

## 3 Results and Discussions

The university comprises a total of 12 hostels, which generate a huge amount of food waste per day and are either drained or taken by the pig bearers of the locality. The present energy (LPG) consumption pattern of waste generation of the hostels is shown in Table 1. The minimum monthly requirement in case of men's hostel is 1 cylinder/day, whereas that of women's hostel is 0.7 cylinders/day. The per capita consumption of LPG was found to be in the range of 3.03–4.96 MJ per day which corresponds to Pobitora Madam Curie women's hostel and Saraighat CV Raman men's hostel, respectively. The average per capita consumption of LPG was found to be 3.92 MJ per day. The daily requirement in the hostels estimates at an average of 1.5–2 cylinders aggregating an average of around 36 to 40 cylinders per month.

### 3.1 Installation of the Plant

The construction of the plant started in September 2013 under the supervision of technician from VK-NARDEP, Kanyakumari. The various phases of construction are shown in Fig. 1 below. The construction of the gas holder was done initially by fabricating the structure with MS rod and tin plates and then reinforcing it with fibreglass-reinforced plastic (FRP). The entire process took 2 months to complete.

**Table 1** LPG consumption pattern in different hostels in Tezpur University

Hostel	No. of boarders	Approximate number of cylinders required/day	MJ equivalent of LPG	Energy density (MJ/capita)	Food waste available (kg/day)
Saraighat CV Raman men's Hostel	350	1.06	693.90	4.96	95
Patkai Men's Hostel	386	2.16	1413.98	3.66	92
Charaideo Men's Hostel	270	1.55	1014.66	3.76	112
Nilachal Men's Hostel	411	2.16	1413.98	3.44	74
Kanchenjunga Men's Hostel	390	2.16	1413.98	3.63	139
Dhansiri Women's Hostel	139	0.91	595.70	4.29	32
Pragjyotika Women's Hostel	136	1.00	654.62	4.81	30
Bordoichila Women's Hostel	104	0.70	458.23	4.41	24
Suwansiri Women's Hostel	183	1.00	654.62	3.58	49
Kopili Women's Hostel	186	1.00	654.62	3.52	44
Pobitora Madam Curie Women's Hostel	316	1.00	654.62	3.03	88
New Women's Hostel	126	0.78	510.60	4.05	25

### 3.2 Feedstock Characterization

The feedstock mainly food waste that were available are characterized as shown in Table 2.

### 3.3 Determination of Biogas Yield

The biogas production of the installed plant was monitored for a period of 2 months. The gas production was also measured in m<sup>3</sup>/kg TS of food waste. During this period, the gas production was in the range of 0.2–0.5 m<sup>3</sup>/kg TS of food waste. The highest production achieved was 0.63 m<sup>3</sup>/kg TS of food waste, whereas the lowest production was 0.5 m<sup>3</sup>/kg TS. These values directly related to the maximum and minimum feed fed to the plant on the previous day of gas measurement during the period of study.



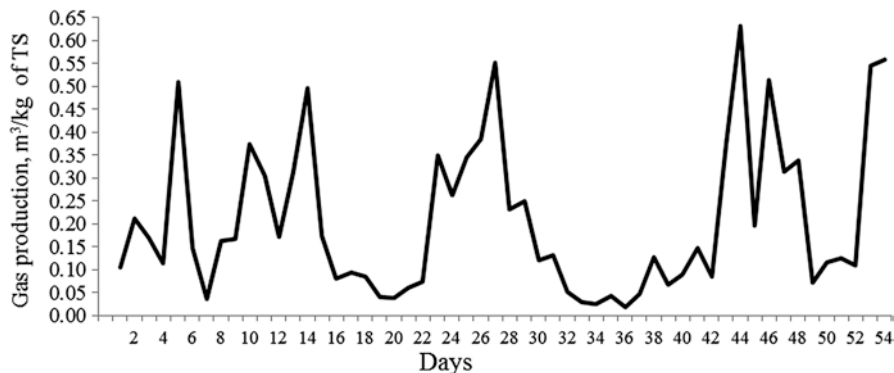
**Fig. 1** (a–d) Construction phase of the biogas plant

**Table 2** Characteristics of the feedstock

Parameter	
Total solid (TS), %	27.17
Ash, % TS	3.6
Total suspended solid (TSS), g/l	250
Total carbon(TC), mg/l	5128.82
Total organic carbon (TOC), mg/l	5073.78
Inorganic carbon	64.06
Total nitrogen (TN), %	3.36
C:N	15

At times when gas production was low, pH of the digestate (residue that remains after digestion) was measured. It was observed that the pH had a direct impact on the production of biogas. The production of biogas was low when the pH of the digestate was in the range of 5–6, and it was comparatively higher when its pH was in the range of 6–7.5. In case of food waste, because of the heterogeneous nature of food, the amount of volatile fatty acid formation is higher during anaerobic digestion process, which hinders the growth of methanogenic bacteria leading to decrease in biogas production. Therefore, when the gas production was found to drop, to





**Fig. 2** Gas production in m<sup>3</sup>/kg total solid of food waste over a period of 54 days

raise the pH, cow dung was fed to the digester until the pH of the digestate rose to 7. Figure 2 shows the gas production in m<sup>3</sup>/kg total solid of food waste for the period of study.

### 3.4 Variation of Methane Content of Biogas

The composition of biogas in terms of methane content (%V/V) was measured using a biogas analyser. The calibration was done by analysing the biogas sample with GC, and the % of CH<sub>4</sub> obtained was set in the biogas analyser using the same sample of biogas.

The CH<sub>4</sub> was studied for a period of 36 days. It was seen that initially the CH<sub>4</sub> was in the range of 45.8%, and gradually it decreased to 30.1% at which the burner emitted yellow flame and even stopped burning due to high concentration of CO<sub>2</sub> in the biogas. Therefore, feeding was done with cow dung to make the system stabilized. Cow dung feeding increased the % of CH<sub>4</sub>. Once the system was stabilized again, food waste feeding was started. During the period of the study, the highest % of CH<sub>4</sub> obtained was 55.20%. The overall % changes of CH<sub>4</sub> are shown in Fig. 3.

### 3.5 Determination of Equivalent Amount of LPG

For the determination of equivalent amount of LPG, the test was carried out on four different days. And due to the variation of CH<sub>4</sub> (%), there was slight variation in the amount of equivalent LPG obtained. It was found that 1 m<sup>3</sup> of biogas is equivalent to 0.25–0.35 kg of LPG w.r.t. prevailing conditions of the system.



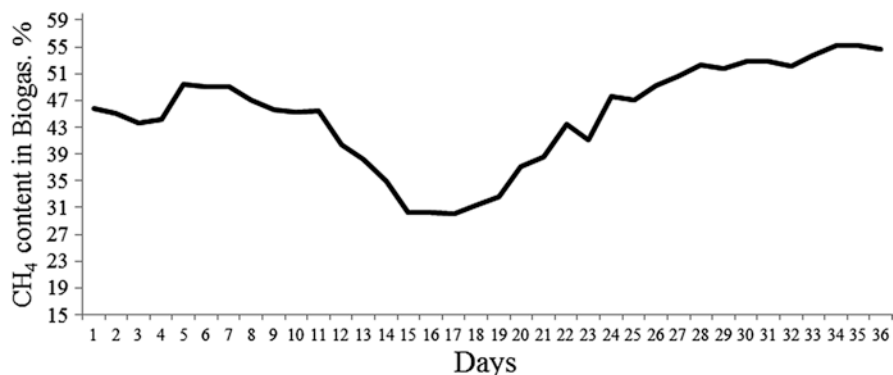


Fig. 3 Variation of CH<sub>4</sub> (%) content of biogas

Table 3 Overall benefits and costs for 10 years

Year	Capital cost (Rs)	Overall maintenance cost			LPG saving (Rs/annum)	Gross expenses (Rs/annum)	Cumulative saving (Rs/annum)
		Electricity cost (Rs/annum)	Labour wage (Rs/annum)	Maintenance Cost (Rs/annum)			
1	1,000,000	5395	18,000	10,000	148,920	1,033,395	-884,475
2		5638	18,810	10,450	155,621	34,898	-763,752
3		5892	19,656	10,920	162,624	36,468	-637,597
4		6157	20,540	11,411	169,942	38,109	-505,764
5		6434	21,465	11,925	177,589	39,824	-367,999
6		6723	22,431	12,461	185,581	41,617	-224,035
7		7026	23,440	13,022	193,932	43,489	-73,592
8		7342	24,495	13,608	202,659	45,446	83,620
9		7673	25,597	14,221	211,779	47,491	247,907
10		8018	26,749	14,860	221,309	49,629	419,587

### 3.6 Economic Analysis of the Biogas Plant

As per the version of Vivekananda Kendra – Natural Resources Development Project (VK-NARDEP), the daily amount of biogas generated would be equivalent to approximately 30 cylinders per month. But during the experimentation stage, the maximum amount of LPG cylinder that could be saved during a month was found to be 14. This may be due to the acidic nature of heterogeneous food waste fed to the plant, which eventually hindered methanogenic bacteria growth, and biogas generation was low. As the plant was in the experimentation stage, the exact amount of LPG saving cannot be estimated. As per the calculations made, an average of ten LPG cylinders can be saved in a month considering the proper condition of the biogas plant. The overall cost analysis is shown in the Table 3. It can be seen that the payback period of the biogas plant is 7.36 years (Table 3).

## 4 Conclusions

Cooking energy consumption is expected to increase with continuous increase in the population of Tezpur University. Considering this, renewable energy-based cooking energy (biogas) could be a viable option to supplement the daily energy needs in the future. The present study was based on the feasibility study of implementing biogas-based cooking from kitchen waste in one of the hostels at Tezpur University. Performance analysis and economic assessment of the 50 m<sup>3</sup> biomethanation plant showed that it can be a workable option for utilization of the food waste generated in educational institutions through production of clean cooking fuel 'biogas'. However, proper monitoring of feeding rate and quality is critical for smooth performance of the biogas system.

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