

## GE02

# Supplementing energy demand of rural households in Bangladesh through appropriate biogas technology

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**Abstract—** This paper has sought to show the potential of energy recovery from rurally available agro and household organic wastes and thus, the possible impact on supplementing energy demand, reducing deforestation, and replacing fossil fuel as well as avoided greenhouse gases. Results show that co-digestion of a wide range of manure, crop residues and household wastes with cow manure was successful to produce increased gas yield than what would be if cow dung is digested separately and the energy value from this can supplement 57–79% of the rural energy demand, depending on the methane yield from organic waste mixtures. However, particularly considering for cooking purpose, it can save 1586–2213 Kg firewood/Household/year. Therefore, the results suggests that implementation of co-digestion in the centralized plant could be a viable solution to produce decentralized energy for the rural households in terms of sustainable waste management, reducing deforestation as well as replacing fossil fuels.

### INTRODUCTION

The rural areas of Bangladesh, which are inhibited by about 65% of total population, have relatively little or no connection with the national power grid. Rural people meet up the energy needs mostly from traditional biomass fuels comprising of agricultural residues (45%), wood and wood wastes (35%), and animal dung (20%). Generally biomass is estimated to account for over half (~62%) of the country's energy consumption [1]. However, extensive burning of biomass resources, especially biomass-fired cooking stoves used to be end up with a low efficient (= 5–15% efficiency) energy production [2], may lead to high pressure on the forest resources, air pollution from smoke, public health hazard (e.g., eye infection, respiratory disease and coughing), and uneconomic use of garbage and household wastes. It should be noted that organic recycling in Bangladesh is only ~11% compared to 40% and 65% in India and China, respectively [3], which could be due to the over exploitation of biomass fuels through burning beyond their regenerative limits. Against this background, biogas technology could be a right option to supplement the energy demand in rural areas. Therefore, the interest in biogas technology as low cost and "low-tech" option of renewable energy source has garnered attention in many developing countries. For example, India and Nepal have installed 3.71 and 0.11 million family size biogas plants

against the estimated capacity of 12 and 1.3 million, respectively [4] - [5]. However, there are only 35,000 biogas plants in Bangladesh despite the great potential for an expansion up to 4 million plants [1], [6].

There is family run biogas technology in the rural areas of Bangladesh, which is primarily based on cow dung. Moreover, other organic wastes such as chicken litter, household organic wastes and crop residues are accessible, but none of these substrates is suitable to run biogas plant due to insufficient quantity and year-round unavailability. However, in a centralized facility (e.g. community or municipality based biogas plant) with co-digestion, cow dung could be co-digested with those other available substrates, which can establish an economic utilization of a range of unused organic wastes. Both of these concepts are not new and are widely using in many parts of the world for processing organic wastes [7] and represent today an integrated system of manure and organic waste treatment, nutrient recycling and renewable energy production, generating intertwined agricultural and environmental benefits [8]. So, there is possibility of adding value to a wide range of available organic wastes in terms of energy recovery. This paper is aimed to estimate bio-energy production from available rural organic wastes in order to predict how much of the rural energy demand could be supplemented in this way as well as to identify possible impacts e.g. saving of traditional fuels, reduction of greenhouse gases, improvement of environmental quality. In this regard, anaerobic digestion experiments were carried out to identify methane yield of cow manure based agro and household waste mixtures, and the present energy demand, use of fuel type, and waste composition in a number of project areas situated in the Rangpur region, Bangladesh have been used as a representative for the rural areas.

### METHODOLOGY

#### *Methane yield of organic waste*

Experiments were carried out for assessing biogas and methane yield from different agro and household waste materials as well as mixtures of these under both bench-scale and full-scale conditions. In both cases, materials were selected based on the average waste composition of the project areas in the Rangpur region, where Rangpur-Dinajpur Rural Service (RDRS), a national

humanitarian and development NGO, is working on the implementation of biogas plants in collaboration with DanChurchAid, a Danish humanitarian NGO. According to a survey by RDRS involving 721 families, waste from the area consists of 71% cow dung, 7% chicken litter, 3% sheep/goat manure, 6% food waste, 13% leaves/straw (wet weight) [9]. Bench-scale experiments were carried out at Aalborg University, Denmark, under controlled laboratory conditions to identify the gas yield and full-scale digestion experiments were carried out under local conditions in order to re-evaluate the methane yield from selected material mixtures, in Kawnia village, Rangpur district, Bangladesh in three small-scale biogas plants [10]-[11], supplying 1.6–2 Nm<sup>3</sup> biogas per day. Details of materials preparation for digestion experiment and results obtained are outlined in [18]. Analyses of the materials collected in Bangladesh were done at Bangladesh University of Engineering and Technology (BUET), Dhaka. Mixture materials were prepared manually in order to investigate the effect of adding other available materials with the most abundant material i.e. cow dung at the project area, with regard to biogas potential. In this respect, one mixture substrate (M<sub>0</sub>) consisting of 32% chicken litter, 12% sheep manure, 24% food waste and 32% leaves/straw (wet weight) was prepared according to the waste composition in the Rangpur region. Five additional mixture substrates (M<sub>1</sub>–M<sub>5</sub>) were then prepared from M<sub>0</sub> and cow dung at cow dung: M<sub>0</sub> ratios of 80:20, 70:30, 65:35, 60:40, and 55:45 (wet weight). This range corresponds to the range of waste compositions available in most of the rural areas in Bangladesh. The characteristics of mixture materials and identified gas yield from both experiments are shown in Table 1.

#### Data used

The estimation of energy demand of rural household is based on the present fuel use pattern of the project areas in the Rangpur region (Fig. 1), obtained from a survey by RDRS Bangladesh. According to this survey, rural households, in most cases, use biomass fuels such as firewood, dried cow dung, crop residues for cooking purpose, and kerosene for lighting purpose. To obtain the energy demand at household level, several conversion parameters have been used (Table 2). Two parameters such as energy and greenhouse gases (GHGs) have taken into consideration in order to evaluate the importance of utilizing organic wastes through biogas production. In this regard, methane yields from Table 1 and conversion parameters from literature to estimate energy from methane, fossil fuel (coal) have been used. All the necessary calculations have been done per household (HH) per year as well as per ton of materials and parameters used for calculation are listed in Table 2.

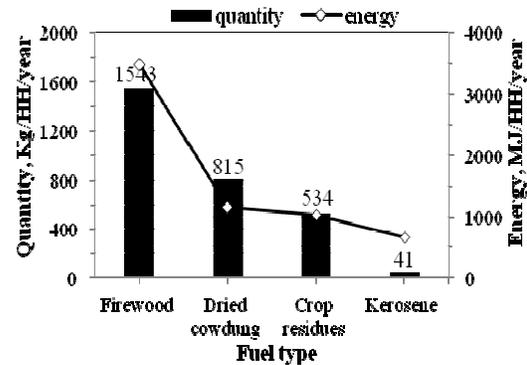


Fig. 1 Current status of fuel use and energy consumption pattern in rural areas

## RESULTS AND DISCUSSIONS

From the Table 1, it is evident that biogas production and methane yield of the mixture substrates (M<sub>1</sub>–M<sub>5</sub>) are fairly similar in case of both bench-scale and full-scale experiments and the results indicate that mixture of different agro and household wastes with the co-digestion of cow dung can be successfully used in full-scale biogas plants to improve biogas production than what would be if cow dung is digested separately. This means that in a centralized facility with co-digestion, cow dung could be co-digested with other available organic wastes (such as chicken litter, household organic waste, crop residue) and thereby, the opportunity to deal with a wide range of organic wastes, which are not utilized at present, can be established through anaerobic co-digestion.

According to Fig. 1, more than 50% of the current fuel use requirement at rural household is met via burning of firewood, reflecting the strong dependency on firewood. Due to quite low efficiency (5–15%) of traditional cooking stoves, huge quantities of biomass fuels are wasted. So the actual consumption of energy should be much lower than the energy content of the required quantity of biomass fuels depending on the efficiency of cooking stove. Based on the efficiency of cooking stoves, lighting lamps and energy content of biomass fuels and kerosene (Table 2), the energy demand for cooking and lighting purposes have been estimated as 5674.6 and 656.7 MJ/HH/year, respectively, resulting in total energy demand of 6.33 GJ/HH/year.

In a case study of Bangladesh about energy from biomass, it was reported that useful energy consumption based on socio-economic class of rural areas ranged between 2.3–5.2 GJ/HH/year [12], which is comparable with the findings in the present study. These results indicate the strong dependency on burning biomass fuels for cooking purpose, which is about 90% of the total energy demand at rural household level. However, estimation of energy recovery via methane yield from available agro and household wastes (annual availability 4568.5 Kg/HH) showed that available energy for cooking is 3.6–5 GJ/HH/year, which is about 57–79% of the energy demand. If this recoverable energy is only used for cooking purpose,

then it can supplement about 63–88% of the rural energy demand for cooking purpose only, which would result in a saving of 1586–2213 Kg firewood/HH/year

thereby, reduce global warming potential. Simultaneously, a sustainable biomass waste management could be achieved in this regard. Methane yield per ton of mixture

**Table 1.** Characteristics of cow dung and mixture materials and their gas yield

Substrate	Dry matter (DM) content (% wt.)		Volatile solids (VS) content (% wt.)		Biogas yield (L/Kg VS)		Methane yield (L/Kg VS)	
	Bench-scale	Full-scale	Bench-scale	Full-scale	Bench-scale	Full-scale	Bench-scale	Full-scale
Cow dung	13.8	25.2	11.5	20.2	302	392	133	172
<sup>a</sup> M <sub>1</sub>	24.2	30.8	18.2	24.5	428	415	196	191
<sup>b</sup> M <sub>2</sub>	28.9	–	20.9	–	386	–	189	–
<sup>c</sup> M <sub>3</sub>	30.0	33.8	21.7	26.9	468	447	211	201
<sup>d</sup> M <sub>4</sub>	32.0	–	22.3	–	436	–	201	–
<sup>e</sup> M <sub>5</sub>	34.5	–	22.7	–	452	–	220	–

M<sub>0</sub> = 32% chicken litter + 12% sheep manure + 24 % food wastes + 32% leaves&straw (by weight)

<sup>a</sup>M<sub>1</sub> = 80% cow dung + 20% M<sub>0</sub>; <sup>b</sup>M<sub>2</sub> = 70% cow dung + 30% M<sub>0</sub>; <sup>c</sup>M<sub>3</sub> = 65% cow dung + 35% M<sub>0</sub>

<sup>d</sup>M<sub>4</sub> = 60% cow dung + 40% M<sub>0</sub>; <sup>e</sup>M<sub>5</sub> = 55% cow dung + 45% M<sub>0</sub>; (–) data not measured

**Table 2.** Parameters used for calculation

Parameters	Value	Reference
Efficiency of biomass cooking stove	15%	[2]
Efficiency of kerosene lighting lamp	35%	Assumed based on 2 no. 60 Watt@4.15 hours for 1 year/HH
Energy content of traditional biomass fuels	<sup>1</sup> Firewood: 15 MJ/Kg, <sup>2</sup> Agricultural residues: 13 MJ/Kg, <sup>3</sup> Dried cow dung: 9.5 MJ/Kg, <sup>4</sup> Kerosene: 46.2 MJ/Kg	–
Methane energy content	55.5 MJ/Kg	[15]
Coal energy content	31 MJ/Kg	[16]
Density of methane	0.71 Kg/m <sup>3</sup>	[15]
CO <sub>2</sub> emission from coal combustion	3.7 Kg CO <sub>2</sub> /Kg	[16]
Efficiency, power generation from coal	45%	[16]
Biogas burner efficiency	55%	[17]

<sup>1</sup>[http://en.wikipedia.org/wiki/Heat\\_of\\_combustion](http://en.wikipedia.org/wiki/Heat_of_combustion); <sup>2</sup>[http://bioenergy.oml.gov/papers/misc/energy\\_conv.html](http://bioenergy.oml.gov/papers/misc/energy_conv.html)

<sup>3</sup><http://tammi.tamu.edu/ManurtoEnrgyE428.pdf>; <sup>4</sup><http://en.wikipedia.org/wiki/Kerosene>

This range can be comparable with the one reported in the technical study of biogas plants installed in Bangladesh, where the firewood saving was estimated to be 1660 Kg/HH/year due to benefit from biogas [13]. Moreover, in terms of reducing GHGs emission, biomass utilization through biogas production also contributes to some extent.

For instance, if combustion of coal is considered to meet the energy demand at the project areas, then it would require 454 Kg coal/HH/year and consequently, would cause emission of 1680 Kg CO<sub>2</sub>/HH/year. This in turn results, pressure on using fossil fuel as well as on global warming. Also using coal combustion would result in increased dumping of biomass materials into landfills, which will cause increased demand of open space for future dumping, GHGs emission, and groundwater pollution through leaching. However, as estimated, 57–79% usable energy recovery per HH per year through biogas could supplement a major portion of using coal and

substrate shows that usable energy for cooking could be 781–1090 MJ/ton substrate, which is equivalent to substitute 56–78 Kg coal or 347–484 Kg firewood as well as an avoided emission of 207–289 Kg CO<sub>2</sub> (if coal is combusted), depending on the methane potential of mixtures.

Therefore, energy recovery from available biomass materials through biogas production can be a strong alternative option to supplement rural energy demand, which can consequently reduce deforestation as well as use of fossil fuels. The by-product from biogas production could also be a potential source of organic fertilizer, which can be used for soil amendment and can replace the use of chemical fertilizer. However, the implementation of family size biogas plants (currently available system) was not successful in the past two decades in many rural parts of Bangladesh, mainly because of design, construction and

maintenance problems, and limited research and development capabilities as well as limited coordination among researchers and implementing authorities [14]. But initiative to promote biogas technology among local entrepreneurs and establishing centralized biogas plant (e.g. community or municipality based biogas plants) with proper design and coordination could be a suitable option and in this regard, co-digestion of available biomass materials could be a promising option to improve biogas yield, as evident from both bench-scale and full-scale study results.

#### CONCLUSIONS

The estimation of energy demand at rural household level and the possible option to supplement a major portion (57-79%) of this through bio-energy, as calculated in this study, are fairly comparable with some previous studies. The findings could be of real significance that can popularize biogas technology as a mean of decentralized energy production. Nevertheless, implementation of appropriate biogas technology (e.g. co-digestion in the centralized plant) is necessary this to be an optimistic alternative to supplement rural energy demand.

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