Hydrogen Energy Storage Based Biogas Power Plant in Bangladesh: Design and Optimal Cost Analysis

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***Abstract*—Energy demand has been rising sharply over the years around the globe. The era of fossil fuels is almost at its lattermost phase. Now renewable energy is creating a greater transformation in the global energy landscape. With its enormous population, Bangladesh is currently facing impending energy scarcity. Usage of sustainable and eco-friendly energy sources is the only way out of this emergency. In this paper, we have introduced a hybrid power plant consisting of biogas and Hydrogen energy and both of them belong to renewable energy sources. In Bangladesh, the agriculture sector's performance has been firmly flourishing in recent years and about 60 percent of overall agricultural output comes from the crops sub-sector like livestock and fisheries. We have chosen the Nahar Agro cattle farm situated in Mirsarai Upazilla of Chattogram as a project area for its decent amount of animal manure availability. The main objective of this proposed design is to attain a peak load demand of 25 kg/day in Chattogram and attain energy security without harming mother nature. The total generated Hydrogen is about 9350 kg/year which will fulfill a fraction of Hydrogen demand in the upcoming days and about 73865 kg generated by-product oxygen will help the nation greatly to overcome the medical oxygen crisis. The system design is optimized in HOMER Pro software**

***Keywords*— Renewable energy, Biogas plant, Hydrogen, Oxygen, Homer Pro Software**

I. INTRODUCTION

Bangladesh is a country in South–Asia. Because it is one of the most densely populated countries in the world, it can hardly generate energy in proportion to its energy demand. But Bangladesh is much fortunate to have an abundant number of renewable sources including solar, wind, biomass, hydro, geothermal, biogas, etc. [1]. The Bangladeshi government has set a target to generate 200 MW of electrical power sources by 2021, while the new renewable energy target would be 10% of the total electricity generation in 2021 and would increase to 20% by 2030[2]. Despite having benefits, the implementation of renewable power plants is not possible on a larger scale because of its enormous installation and maintenance cost. It is even harder for developing and underdeveloped countries. Among the renewable sources, biogas belongs to the cheaper category. Also, as an agricultural country, Bangladesh has a bright future in the biogas sector. Biogas is one kind of biofuel produced by decomposing various kinds of organic matter. Biogas can be used for heating, cooking, electricity production, etc. It is estimated to have to potential to replace vehicle fuel in the near future. At the same time, Hydrogen is a clean and flexible energy source that supports zero carbon emission. Hydrogen fuel can provide motive power for liquid-propellant rockets, cars, trucks, trains, boats, and airplanes, portable fuel cell applications, or stationary fuel cell applications, which can power an electric motor [3]. Furthermore, Hydrogen has many superior properties as an energy carrier and has a high energy density (140 MJ/kg) which is more than two times higher than typical solid fuels (50 MJ/kg [4]. Which is one of the highest, but Hydrogen production via this process is very expensive. So, in this paper, we have proposed a hybrid power plant where we will use biogas to produce the most power-effective Hydrogen fuel least expensive way.

Our proposed project area (Longitude = 22.845728, Latitude = 91.554742) is situated near the cattle farm in Chattogram, Bangladesh. Muck will be collected from about 3800 cattle that are being fostered inside Nahar Agro cattle farm which is about 200 meters far from the project and dung will be put into the digester to undergo anaerobic digestion and produce biogas to be used as the power source for Hydrogen power plant. As a developing country, Bangladesh is continuously facing energy shortages and during this pandemic, the Oxygen supply has stretched to its limit. There is a daily demand for 180 tons of Oxygen for hospitals and other related industries and the majority portion of that is being imported from abroad [5].

In this paper, we have envisioned a hybrid power plant where the electricity produced by biogas will be used to produce hydrogen (H2) which has high efficiency and low environmental impact, and oxygen(O2) which will save millions of lives. It will aid the nation to overcome power crisis as well as ensure public health and security

II. SYSTEM METHODOLOGY

In this system methodology section, we will show the whole procedure of the proposed plan model that how we can use biogas for producing Hydrogen fuel where Oxygen will be generated as a by-product. We have used organic raw material (cattle dung) for the anaerobic digestion process (ADP). The cattle dung should be given into the fermenter and water will be added from water storage by a pipe for ADP. After completing the ADP, biogas will be generated gradually. From the fermenter, the generated biogas will be collected by a gas pipe. Collected biogas must go through the purification process because it contains non-required gases and particles. Only after the purification process will the biogas be eligible to be used as biofuel for producing electricity. So, after finishing the process the purified biogas will be stored in gas storage, and now it can be used to start the DC biogas generator to generate electricity. After doing so, this electricity will be supplied to the electrolyzer. The point to be noted is that there is no need for a converter because of using a DC system. The water supply has to connect with the electrolyzer because the targeted Hydrogen and Oxygen will be generated after water electrolyzes. After the water supply connection is established, the electrolysis process will be initiated and Hydrogen(H2) and Oxygen(O2) will be generated at the same time. Generated Hydrogen (H2) and Oxygen (O2) will be stored in two individual storages (Hydrogen Tank and Oxygen Tank). So, using this methodology, we can produce Hydrogen and Oxygen from our proposed system.

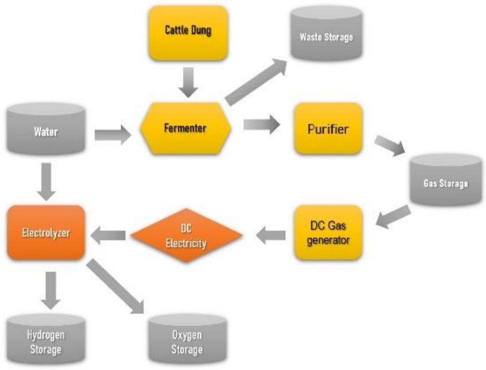


Fig. 1 Schematic view of the proposed system

III. BIOGAS TECHNOLOGY

As the biogas is the key fuel of our proposed plant, in this section biogas technology-related detailed information is stated in two subsections A & B.

A. *Biogas And It's Composition*

Biogas is a mixture of gases. It's produced when organic matter, such as food or animal waste, is broken down by microorganisms in the absence of oxygen, in a process called anaerobic digestion [6]. Using enzymes generated by fermentative bacteria, complex polymers are turned into soluble products and produce biogas. Carbon dioxide, Hydrogen, and short-chain fatty acids are the components that are produced through the breakdown [7]. The composition of the gases depends on the substances being decomposed [8]. The components vary depending on the anaerobic reactor (temperature pH, substrate concentration) [9]. The typical composition of biogas is given below in table I.

TABLE I. COMPOSITION OF BIOGAS [6]

Components	Percentage
Methane (CH_4)	60-70
Carbon dioxide (CO_2)	30-40
Hydrogen (H_2)	2-2.5
Nitrogen (N_2)	1-1.5
Oxygen (O_2)	0.3-0.4
Hydrogen Sulfide (H_2S)	0.1-0.2

B. *Temperature Control System*

Since a bacterial anaerobic degradation process produces biogas, it requires certain environmental conditions. The temperature has a profound influence on the rate of biogas production. Choosing the temperature blindly ultimately results in the death of bacteria or a decrease in bacterial activity at the least. The normal requirement of temperature for anaerobic digestion is 30℃ to 70℃. The optimum temperature should be Between 35℃ to 37℃ since the temperature is crucial a temperature control system can be implemented inside the digester. An electric heater AND thermal sensor will be installed inside the digester in this system. The thermal sensor will monitor the temperature of the digester simultaneously, and if the temperature is measured to be out of the optimal zone, the heater will be used remotely to maintain the required temperature.

IV. PROPOSED PLANT MODEL

The proposed model includes Biogas as a primary renewable source. Furthermore, the model consists of a fermenter, generator, electrolyzer, tank, and hydrogen generator. The location of the proposed plan is shown in table II, and table III shows the specifications of the proposed plant. The total plant volume is 6154m^3, whereas the digester volume and gas holder volume are 4598m^3 and 1556m^3.

TABLE II. PROPOSED PLANT LOCATION

Location	**Nahar Agro Group Cattle Farm, Mirsharai,Chattogram, Bangladesh**
Latitude	22.845728
Longitude	91.554742

TABLE III. PROPOSED PLANT SPECIFICATION

S. No	**Parameters**	**Description**
2	Cattle dung collected per day	38000 kg
3	Digester volume calculated	4598 m^3
4	Volume of gas holder drum	1556 m^3
7	Total plant volume	6154 m^3
6	Biogas production	2470 m^3
7	Generic biogas genset	100 kW
8	Generic Electrolyzer	50 kW
9	Hydrogen storage tank	7000 kg
10	Cattle's available at	3800

V. SIMULATION RESULTS AND COST ANALYSIS

Homer Pro software is used for the simulation of this proposed plan model.

A. Input Parameters for Simulation

As biogas is the fuel input, parameters like gasification ratio, lower heating value, and carbon content are required to simulate in Homer Pro software. The parameter values [10] that are used in this study are given in table IV.

TABLE IV. PARAMETERS OF BIOGAS RESOURCE USED AS INPUT

S. No	Input Parameters	Value
1	Gasification Ratio	0.07 kg/kg
2	Lower Heating Value (LHV)	20 MJ/kg
3	Carbon Content	50%
4	Average Price of Biomass ($/t)	0.00

Table 5 includes the financial parameters that are used in this study. The table consists of capital cost, operation and maintenance cost, lifetime, inflation rate [11] and discount rate. The parameter values are shown in the table V.

TABLE V. FINANCIAL PARAMETERS USED IN THIS STUDY

S. No	Parameters	Value
1	Capital Cost of Biogas Power Plant ($)	155659.78
2	Operation & Maintenance Cost ($/Y)	2900
3	Life Time	20 Years
4	Inflation Rate	5.68 %
5	Discount Rate	8 %

Our aim to meet peak load demand of Chattogram. The daily demand is 25 kg and total demand in a year is 9125 kg. Fig 2 displays the Hydrogen peak load demand of Chattogram.

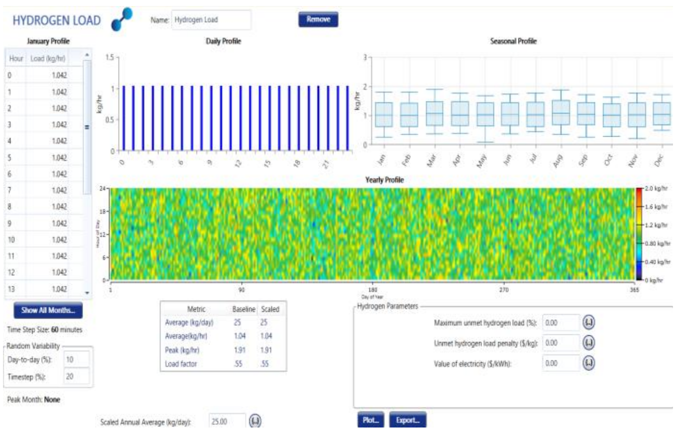


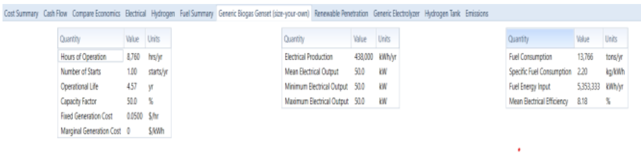
Fig2: Hydrogen peak load demand

B. Optimization Results

The table VI shows the generic 500 kW biogas genset output parameters and their values. Here the electrical production, mean electrical output, Min. electrical output, Max. electrical output and mean electrical efficiency is 434000 kWh/yr, 50.kW, 50 kW, 50 kW and 8.14% .And Fig 3 shows below the Generic 500kW Biogas Genset Output Curve.

TABLE VI. GENERIC 500 kW GENSET OUTPUT PARAMETERS

Quantity	Value	Units
Hours of operation	8760	hrs./yr.
Number of starts	1.00	Starts/yr.
Operational Life	4.57	yr.
Capacity factor	50.0	%
Fixed generation cost	0.05	$/hr.
Marginal generation cost	0.00	$/kWh
Electrical production	434000	kWh/yr.
Mean electrical output	50.0	kW
Min. Electrical output	50.0	kW
Max. Electrical output	50.0	kW
Fuel consumption	13766	L/yr.
Specific fuel consumption	2.20	L/kWh
Fuel energy input	5353333	kWh/yr.
Mean electrical efficiency	8.14	%



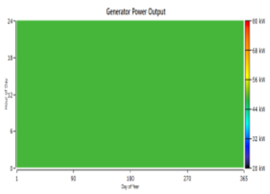


Fig 3: Generic Biogas Genset Output Curve

Table VII shows fuel summary output parameters are total feedstock consumption, avg feedstock per day, and avg feedstock per hour, and the Fuel Summary Curve is shown in Fig 4. The values obtained from the simulations are as follows.

TABLE VII. FUEL SUMMARY OUTPUT PARAMETERS

Quantity	Value	Units
Total feedstock consumed	13766	tons
Avg feedstock per day	37.7	tons/day
Avg feedstock per hour	1.57	tons/hr.

Fig 4: Fuel Summary Curve

In this power plant, we have used a PEM electrolyzer with a rated capacity of 60 kW. Here total input energy is 433891 kwh/yr. and total Hydrogen production is 9350 kg/yr. Electrolyzer Performance Output parameters are depicted below in Table VIII and the output curve is depicted in Fig 5.

TABLE VIII. ELECTROLYZER PERFORMANCE OUTPUT PARAMETERS

Quantity	Value	Units
Rated capacity	60.0	kW
Mean input	49.5	kW
Min. Input	47.9	kW
Max. Input	50.0	kW
Total input energy	433891	kWh/yr.
Capacity Factor	82.6	%
Mean output	1.07	kg/hr.
Min. Output	1.03	kg/hr.
Max. Output	1.08	kg/hr.
Total production	9350	kg/yr.
Specific consumption	46.4	kWh/kg

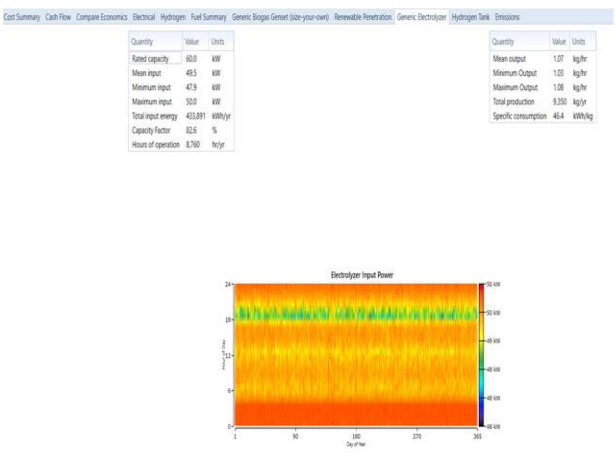


Fig 5: Electrolyzer Performance Output Curve

Fig. 2 shows the Hydrogen production curve for each month throughout the year using Homer pro software.

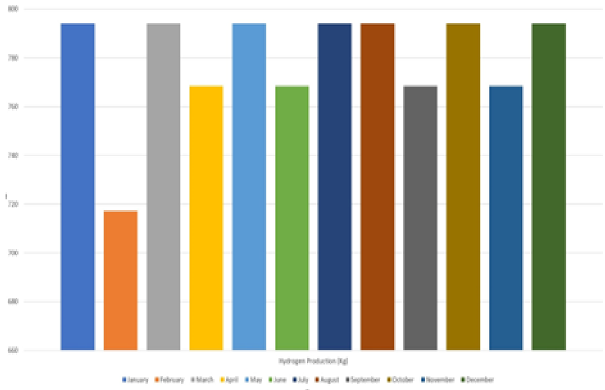


Fig .6 Hydrogen production curve

System production components include biogas production, DC electricity generator, DC electricity consumption, and Hydrogen production obtained from the simulation are 2470m^3/year, 438000 kWh/year, and 9350kg/year, as shown in Table IX. Our daily peak load Hydrogen demand was 25 kg and 9125 kg in a year. In contrast, the total Hydrogen production in this is 9350 kg.

TABLE IX. SYSTEM PRODUCTION

Component	Production(yr.)
Biogas production	2470 m^3
DC electricity generation	438000 kWh
DC electricity consumption	433491 kWh
Hydrogen production	9350 kg

By-product Oxygen production:

From 8.9 liters of water, 1kg of Hydrogen and 7.9 kg of Oxygen can be produced [12].

So, with Pkg of Hydrogen, there will be $(P\times 7.9)$ Kg of Oxygen which is 73865kg.

Where P= Total produced Hydrogen.

C. Cost Analysis

1$=85 TK

Table X Shows the net present cost and table XI shows the annual system cost. Here the net present cost is estimated at 327730.74$, and as for annual system cost, it is estimated 283415$.

TABLE X. NET PRESENT COST

Component	Capital ($)	O&M ($)	Total ($)
Biogas plant	155659.78	46537.46	202197.24
Generic biogas 100 kW genset	24300	7028.76	31328.76
Generic Electrolyzer	91000	1604.74	92604.74

Hydrogen tank	1600	00.0	1600
System	265559.78	55170.96	327730.74

TABLE XI. ANNUALIZED COST

Component	Capital ($)	O&M ($)	Total ($)
Biogas plant	9700	2900	12600
Generic biogas 100 kW genset	1514.26	438	1952.26
Generic Electrolyzer	5670.70	100	5770.70
Hydrogen tank	99.70	0.00	99.70
System	16548.46	3438	20422.67

The overall cost summary is shown in Fig 7.

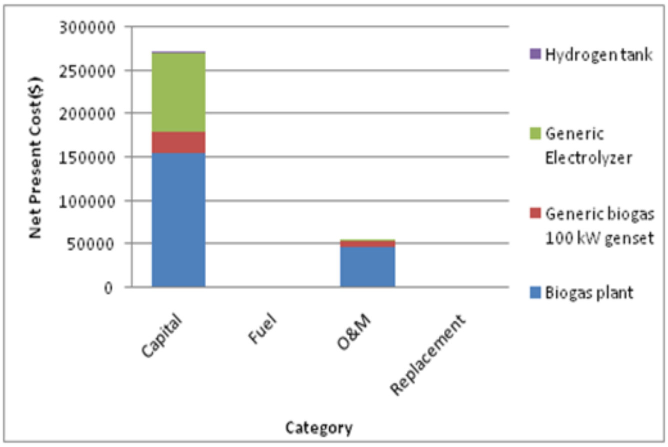


Fig. 7 overall cost summary

VI. CONCLUSION

This study shows the feasibility potential of Hydrogen production using biogas in Chattogram, where the proposed system is easier to install and maintain and cost-effective. The produced Hydrogen fuel is clean and eco-friendly and the by-product Oxygen will fulfill the Oxygen demand of local hospitals as well. As the proposed area is near the farm, the raw material of biogas for the system will be transportation cost-less and convenient to supply. The total net cost for the system is 327730.74$, which may seem high, but to generate Hydrogen fuel, we have estimated the cost per 1kg of Hydrogen is 2.18$, and that is cost-effective in the end.

ACKNOWLEDGMENT

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REFERENCES

[1] Md. Mustafizur Rahman, A.K.M. Sadrul Islam and Md. Abdullah Hil Baky, "Development of renewable energy sector in Bangladesh: Current status and future potentials," Renewable and Sustainable Energy Reviews, vol. 73 , pp. 1184-1197, Jun 2017.

[2] Md. Anisur Rahman Anik, Md. Al-Amin, Md. Abu Bakr Siddique and S. Islam Sharif, "The prospect of renewable energy resources in Bangladesh: A study to achieve the national power demand," Energy and Power , vol. 8, no. 1, pp. 1-6, Jan 2018.

[3] M.Z. Jacobson, D.M. Golden and W.G. Colella, "Switching to a US hydrogen fuel cell vehicle fleet: The resultant change in emissions, energy use, and greenhouse gases," Journal of Power Sources, vol. 150, pp. 150-181, Oct 2005.

[4] J. Chi and H. Yu, "Water electrolysis based on renewable energy for hydrogen ," Chinese Journal of Catalysis, vol. 39, no. 3, pp. 390-394, Mar 2018.

[5] Oxygen supply stretched to limit. [Online]. Available: https://www.thedailystar.net/frontpage/news/oxygen-supply-stretched-limit-2080865?amp. [Accessed: 23-Jan-2022].

[6] What is biogas? [Online]. Available: https://www.nationalgrid.com/stories/energy-explained/what-is-biogas.[Accessed:28-Jan-2022].

[7] P. Jacob Jørgensen . "Plan Energi and Researcher for a Day. Biogas–green energy'–Faculty of Agricultural Sciences, Aarhus University 2009". [Online]. Available: https://www.lemvigbiogas.com/BiogasPJJuk.pdf. [Accessed:02-Feb-2022].

[8] S. D. Hafner and C. Rennuit, Predicting methane and biogas production with the biogas package, 2017.

[9] M. R. Nahian , M. N. Islam, "Prospects and potential of biogas technology in Bangladesh," In 2016 International Conference on Innovations in Science, Engineering and Technology (ICISET), Dhaka,2016, pp. 1-4. doi: 10.1109/ICISET.2016.7856481.

[10] G. P. Sen, B. K. Saxena, and S. Mishra, "Feasibility Analysis of Community Level Biogas Based Power Plant in a Village of Rajasthan," in 2020 International Conference on Advances in Computing, Communication & Materials (ICACCM), Dehradun, India, 2020, pp. 385-389. doi: 10.1109/ICACCM50413.2020.9213073.

[11] Bangladesh: Inflation rate from 1986 to 2026. [Online]. Available: https://www.statista.com/statistics/438363/inflation-rate-in-bangladesh/.[Accessed:05-Mar-2022].

[12] J. Turner and M. K. Mann, Pin-Ching Maness, B. Kroposki, M. Ghirardi, R. J. Evans and D. Blake G. Sverdrup, "Renewable hydrogen production," International journal of energy research, vol. 32, no. 5, pp. 379-407, Apr 2008.