A STUDY ON THE STIRLING GENERATOR: PRODUCING BIOELECTRICITY

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Abstract—*The technology for harnessing power and heat from biomass fuels is already available. Electricity generation from biomass fuels currently uses the same basic technology used in power plants that burn solid fossil fuels. However, new technologies are being developed to improve power production efficiency from biomass. The potential also exists for local sources of electricity production from biomass by using small-scale gasification plants or systems involving fermentation of biomass. By factoring in the pollution-related environmental and social costs generated by fossil and nuclear fuels, bioelectricity becomes a competitive energy source. Here a Stirling generator was used to produce electricity of small scale using biogas as a fuel. The study was done in such a manner that one can get an idea of the internal incidents of the generator such as: different temperatures, engine speed, blower speed, engine power, oxygen sensor data etc. Also a PCA (Portable Combustion Analyzer) of BACHARACH brand was used to investigate the amount of CO, CF (Carbon Monoxide content referenced to 0% O_2), O_2, and CO_2 in the exhaust gas and also the temperatures (ambient and stack), and percentage of combustion efficiency and excess air.*

Keywords—Bio-electricity, Biogas, PCA, Stirling generator.

1. Introduction

A Stirling generator was used to produce electricity of small scale in the rural area of Bangladesh (Tangail and Manikganj) using biogas as a fuel. The project is joint venture of Emergence Energy Inc., USA, BRAC, Bangladesh and DEKA Research and Development Corp., NH, USA. The objectives of this project are to promote renewable energy based electricity to the energy deprived rural Bangladesh and also to test the most recent innovative design of Stirling generator in the real field.

Stirling engine is an old idea. The scientists and researchers in the early 1800 also worked with this technology [6]. The good thing about stirling is that it can work virtually on any fluid which can create heat but the lower efficiency of this engine hinders its growth. But recently there is new revolution in energy sector and with the help of new technology the efficiency of stirling engine can be improved. DEKA, a leading technology development company of USA is currently working with stirling generator and they developed a model, which was being tested in Bangladesh in 2005. The trial period lasted for six month. The stirling generator of DEKA can produce 750W of electricity for four hours using 400cft of biogas daily. It also produces heat that is approx 3 times of electricity output. The biogas was obtained from fermentation of cow dung. The bio-digester was fed with 10000 kg cow dung initially and then 400 kg cow dung daily. It takes two week to produce biogas from the bio-digester. Some advantages of the Stirling generator:

- It runs on virtually any fuel, just need some adjustment.
- Clean and quiet enough to put anywhere.
- Very low maintenance, long life and high reliability.

Figure 1: Front view of Stirling Gen-set..

- Cost competitive.
- Suitable for primary power & as backup power for unreliable grid power.

The generator is a research prototype. And it has an external combustion engine. The working fluid is helium. There is two parts in the generator: a) core chasis, which consists of the engine, and b) auxiliary chasis, which consists the electrical parts and radiator of the generator.

As it is an external combustion engine, there is a burner, which acts as a combustion chamber. The burner burns the fuel and the heat is transferred to the piston-cylinder combination by heat exchanger.

Temperature is measured by two different means. One is with a thermocouple; these are used to read the higher temperatures (head temperature of the burner). They are K-type thermocouples. The other is a thermistor type. These are for the lower temperature (room temp to 100C) measurement. These are used to measure battery temperature, cooler temperature and air temperatures. They are 10k thermistors.

The hot end temperature of the burner is 1000C (approx.). The cold end temperature of the burner is 100C (approx.)

3. Unit Specifications

Different specifications of stirling generator are as follows [1]:

Electrical Output

Maximum continuous engine power (at 70 F) 750 Watts

Temperature derating -2% per 10 F above 70 F Efficiency (output power / LHV fuel) 11.2%

DC output voltage 13.8 Volts

Output current (at full load) 52 A

Other Outputs

Radiator thermal output (at full load) 5.2 kW

Exhaust temperature (at full load) < 260 C / 500 F

Noise 72 dBA at 3m

Dimensions

Core Chassis (H×W×D) = (86.36×58.42×54.61) cm

Auxiliary Chassis (H×W×D) = (86.36×45.72×54.61) cm

2. Block Diagram

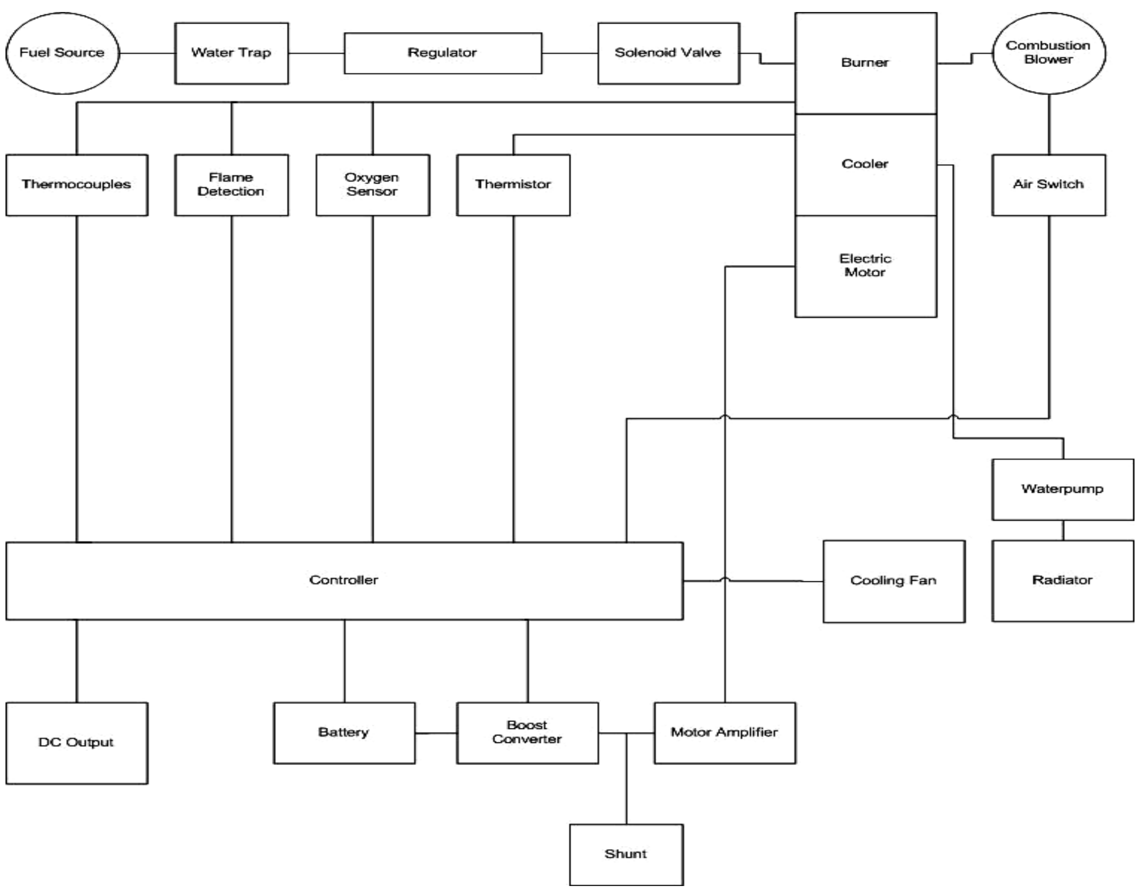

Figure 2: Block Diagram of the system.

Fuel System

Fuel type Propane, Biogas (min 70% CH_4)
Fuel supply pressure ½ psi
Fuel supply inlet 3/8" barb fitting, ¾" NPT

Environment

Operating temperature 13–40 C
Operating humidity 95% relative humidity, non-condensing

4. Power Electronics Block Diagram

The following components are on the power electronics system of the Stirling Gen-set:

1. Motor / Generator

- Normally used as a generator to extract electric power from the Stirling Engine.
- Also used initially as motor to start the Stirling Engine

2. Motor Drive

- Used to control the phasing of currents through the motor / generator

3. Boost / Buck Regulator

- Used to boost voltage from battery to HV Bus
- Also used as buck converter when charging battery from HV bus

4. Battery

- Provides power to start stirling engine
- Used as a hybrid to briefly power loads exceeding the maximum engine power

5. Shunt

- A heating element immersed in the radiator is used to dissipate excess power on the HV Bus when load is suddenly dropped.

6. Output DC/DC Converter

- Provides conditioned power output to the user

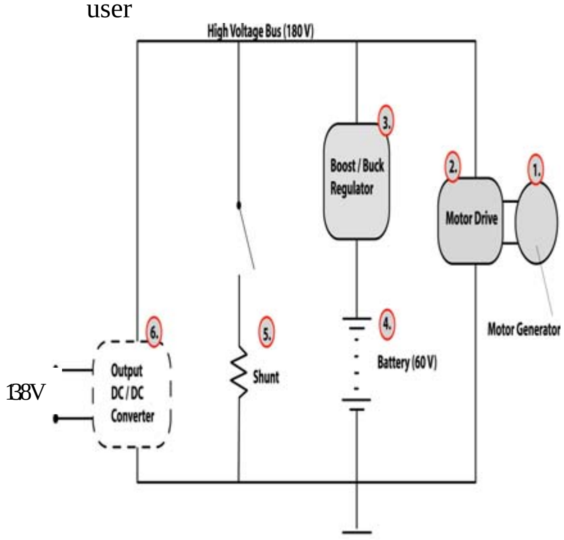

Figure 3: Power Electronics Block Diagram of Stirling Gen-set.

5. System Power Flow / Efficiency

The Village Power unit is an advanced power conversion system that converts the chemical energy stored in the propane fuel into electricity and clean usable heat. It achieves an 11.2% overall efficiency from fuel input to electrical power. When the clean "waste heat" is utilized, the system efficiency approaches 90%. The following diagram visually represents the power flow and efficiency of the Village Power system at full load:

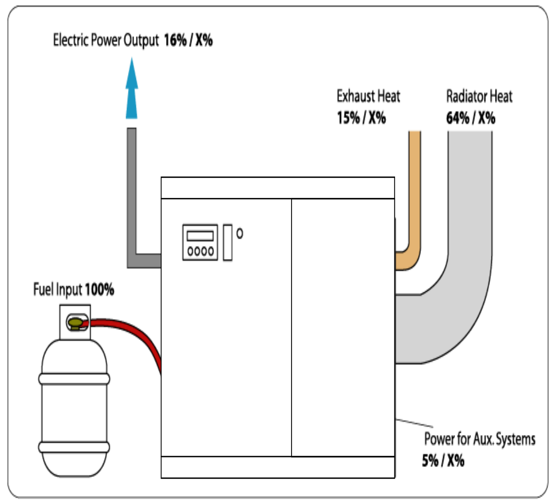

Figure 4: Power Flow / Efficiency Diagram of Stirling Gen-set.

6. User Interface

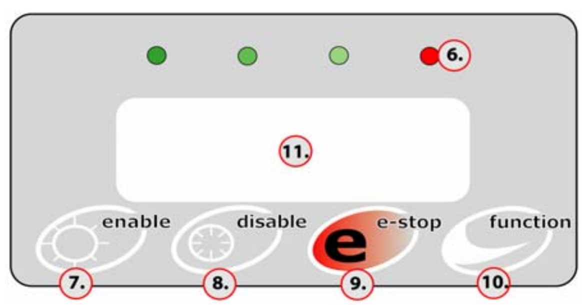

Figure 5: User Interface panel.

The functions of the user interface screen is as follows [1]:

6. LED Status Lights, indicates system mode
7. Enable Button, Re-starts unit, Clears errors/warnings
8. Disable Button, stops unit
9. E-stop Button, shuts down unit without normal protocol
10. Function Button, navigates additional system info

11. Display Screen, shows system status and engine information

7. Studies on Engine Operation

A laptop can be hooked up with the Stirling Gen-set and can get different types of data for biogas and from there different graphs can be drawn.

Table 1: Stirling generator data (speed, temperature etc.) for biogas:

Serial No.	Blower speed (rpm)	Engine speed (rpm)	Ambient temp (C)	Coolant temp (C)	Head temp (C)	Swirler temp (C)	Engine power (W)	Oxygen (%)	Fuel level
1	7821	1994	31.6	40.1	814	585	993.1	1.72	12800
2	8049	1997	31.6	39.8	813	586	954.6	2.06	12800
3	8419	1996	31.7	40.1	812	587	941.1	2.84	12800
4	9371	2078	31.7	39.8	807	586	965.3	3.65	12800
5	10336	2092	31.7	40.0	802	588	970.3	4.35	12800
6	11366	2132	31.7	39.8	799	589	985.1	5.48	12800
7	12455	2158	31.7	40.0	792	590	1028.8	6.20	12800
8	13543	2147	31.7	40.3	793	592	1052.8	6.84	12800
9	13869	2175	31.7	40.0	796	592	1057.4	7.02	12800
10	14862	2203	31.7	40.6	800	593	1052.9	7.55	12800
11	15394	2195	31.7	40.8	801	594	1067.5	7.77	12800
12	15924	2197	31.7	40.4	802	595	1085.9	7.99	12800
13	16647	2238	31.7	40.7	804	596	1102.3	8.28	12800
14	17623	2254	31.7	40.2	805	599	1118.4	8.66	12800
15	18060	2222	31.7	40.7	800	598	1083.2	8.78	12800
16	18571	2281	31.7	40.2	797	598	1130.9	9.03	12800
17	18687	2293	31.7	40.1	796	599	1091.4	9.11	12800
18	18621	2343	31.7	40.0	795	602	1128.0	9.10	12800
19	18619	2368	31.7	40.3	795	603	1122.0	9.00	12800
20	18602	2462	31.8	40.6	796	607	1179.1	9.16	12800

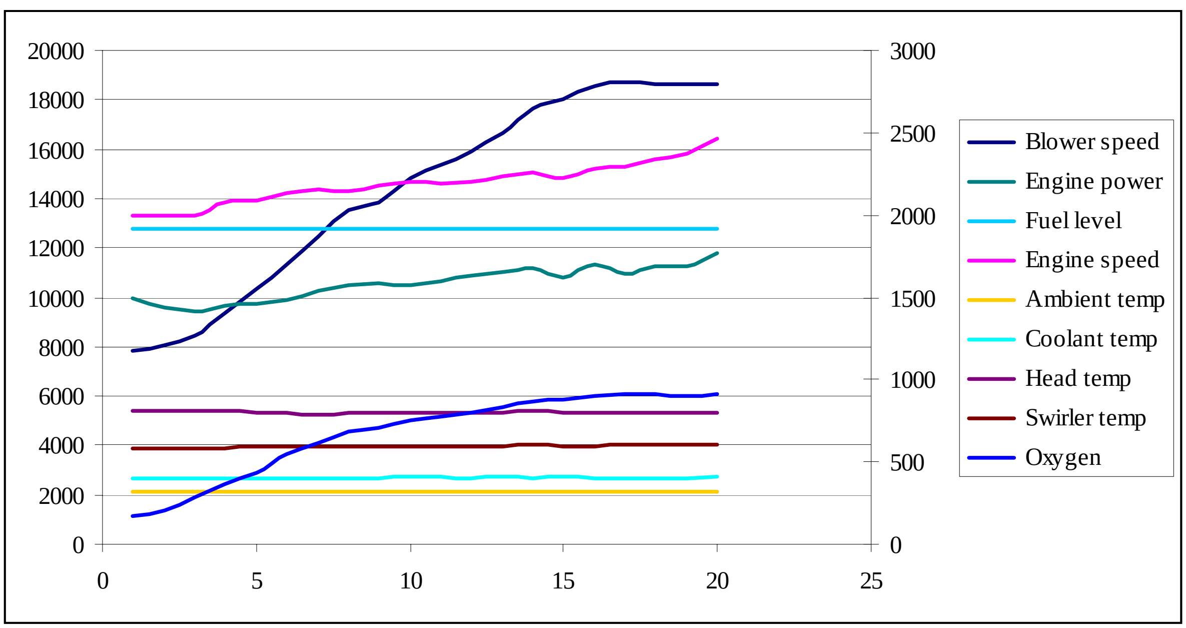

Figure 6: Graph Presentation of different data of Stirling generator for biogas.

A flow meter was used to determine the amount of biogas consumed for a certain time operation of the Stirling generator and from there the running time of the generator with per unit amount of gas can be calculated.

Table 2: Generator running time on biogas and amount of gas consumed:

Serial No.	Running time (Hrs)	Flow meter reading (m^3)	Running time per m^3
1	1.75 hrs	1.9	1.08 hrs
2	2.3 hrs	2.41	1.05 hrs
3	1.5 hrs	1.63	1.086 hrs
4	2.33 hrs	2.4	1.043 hrs

8. Studies on Exhaust Emissions

The exhaust emission was tested by BACHARACH Portable Combustion Analyzer (PCA), (Made in USA).

The part no. was 24-7190, Serial no. was JY-1046 and was calibrated using standards traceable to the National Institute of Standards and Technology on 05th November 2004 and was found to comply with the specified accuracy requirements stated by Bacharach, Inc [7].

The different symbols and there unit used are as follows:

Engine power in watts (data taken from laptop)

Blower speed and Engine speed in rpm (data taken from laptop)

O_2 = % Oxygen
CO_2 = % Carbon Dioxide
TA = Room/Primary Temperature (C)
EF = % Combustion Efficiency
CO = ppm Carbon Monoxide
CF = Carbon Monoxide content referenced to 0% O2 (ppm)
TS = Stack Temperature (C)
EA = % Excess Air

Table 3: Variation of exhaust emissions with time for biogas:

Serial No.	Engine Power (W)	Blower Speed (rpm)	Engine Speed (rpm)	O_2 (%)	CO_2 (%)	CO (ppm)	CF (ppm)	TA (C)	TS (C)	EF (%)	EA (%)
1	632	6000	1515	3.1	11.8	5923	6955	29.5	122	86.9	15
2	604	5990	1485	2.6	12.1	5860	6692	29.5	128	86.8	12
3	691	6020	1501	3	11.8	5838	6817	30	129	86.7	14
4	598	6039	1530	2.8	12	5769	6661	30	130	86.7	13
5	608	6130	1475	3.9	11.2	5781	7107	30	129	86.4	20
6	601	6149	1480	2.8	12	5784	6697	30	131	86.7	13
7	598	6150	1588	2.9	11.9	5886	6834	30	132	86.5	14
8	605	6257	1507	4	11.2	5897	7292	30	128	86.4	20
9	566	6285	1410	3.3	11.6	5917	7026	30	130	86.5	16

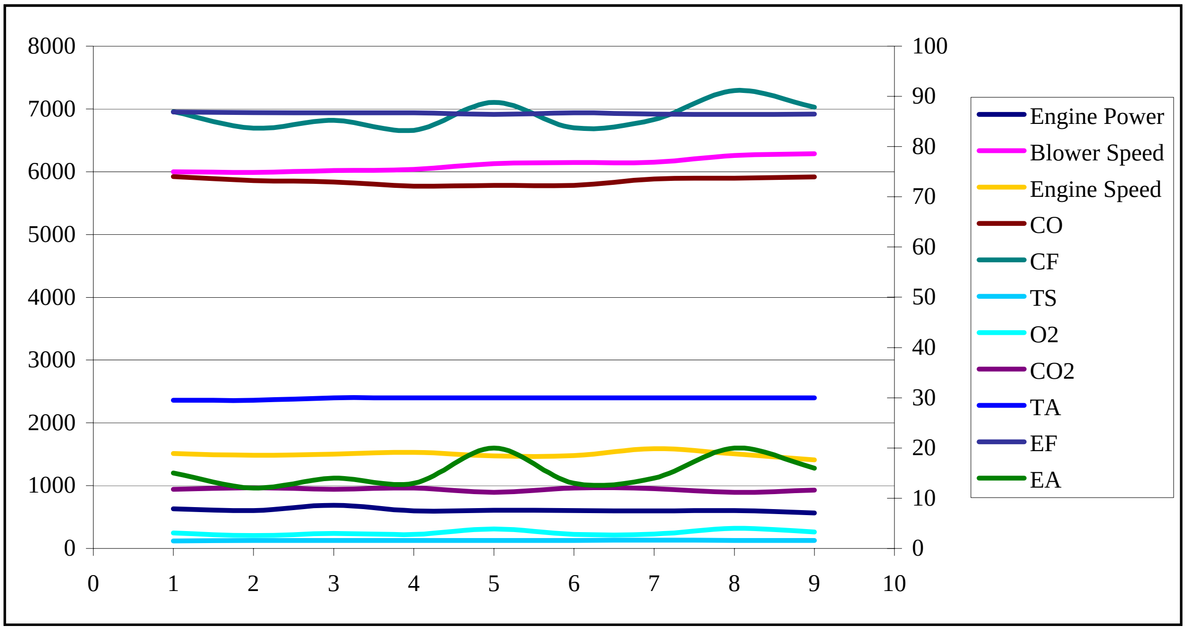

Figure 7: Graph presentation of exhaust emissions for biogas.

9. Defining Bioelectricity

The development of renewable energy sources, including biomass, is fundamental to a sustainable energy future[2]. Biomass could play a significant role as a renewable energy source, and there are a number of reasons that make it an attractive option:

• It can provide a (very) low-carbon source of electricity.
• The use of modern biomass conversion technologies can keep emissions affecting air quality to (very) low levels.
• Suitably managed energy plantations can lead to environmental benefits such as the rehabilitation of degraded lands and the protection of watersheds.
• Its widespread, diverse and renewable nature can contribute to energy security and diversity.
• Its production for energy use can contribute to rural regeneration and development.

10. Sustainability Criteria

In order for biomass to fulfill expectations as a sustainable source of electricity, it must satisfy a number of economic, environmental and social criteria including [5]:

• Biomass must be derived from renewable sources.
• Bioelectricity costs must be kept low to ensure economic efficiency.

• Non-renewable energy inputs to bioelectricity chains must be kept low to ensure low carbon emissions.

• Best available logistics and conversion technologies must be used to reduce emissions affecting air quality.

• Sustainable forestry and agricultural management practices must be followed to avoid negative impacts on soil and water and to foster biodiversity.

• Biomass to electricity schemes must be designed to benefit rural development and gain broad acceptance by the general public.

11. Principles for Environmentally Sustainable Bioelectricity Production

A number of key principles are required to ensure that biomass is produced and used effectively for sustainable electricity production as summarized below [2]:

1. Life Cycle Analysis (LCA) [4] principles should be applied to bioelectricity chains to ensure that any significant impacts are dealt with and benefits are captured.

2. Bioelectricity schemes need to be subject to rigorous Environmental Impact Assessments prior to implementation to address local potential negative impacts and capture value of benefits.

3. Good agricultural/forestry practices must be followed which have been developed to suit local conditions.

4. The continuous development and introduction of new varieties that are suited to local soils and climate is necessary to optimize productivity and minimize inputs.

5. Biomass production practices must protect and/or enhance soil organic matter.

6. Water use should be assessed throughout the production and conversion chain with particular emphasis on impacts on watersheds [3].

7. Best available conversion technologies should be used to minimize emission to air and to other environmental media. Combined heat and power (CHP) systems are preferred.

8. Ash quality from conversion processes should be monitored and efforts made to recycle ashes back to land. Policies and regulation need to be in place to ensure that the above principles are followed. Market incentives that account for the benefits of bioelectricity should contribute towards the viability and profitability of different stages of the fuel chain. Cross-sector cooperation is a pre-requisite to both the establishment of environmentally sustainable biomass production [4] and conversion chains.

12. Advantages

Bioelectricity is a natural fit for the electric power industry. Power plants that co-fire biomass with coal have fewer emissions that cause acid rain. And biomass fuels share some characteristics—such as being available on demand—with coal, oil, and natural gas. Their use meshes well with an industry used to working with fossil fuels.

Bioelectricity is good for the environment. Because biomass fuels are renewable, they help reduce greenhouse gas emissions from fossil fuels. When energy crops are grown for bioelectricity generation, they help preserve our cropland, create habitat for wildlife, and prevent soil erosion.

Bioelectricity makes productive use of crop residues, wood-manufacturing wastes, and the clean portion of urban wastes. These "useless" wastes would otherwise be open-burned, left to rot in fields, or buried in a landfill. Wastes that rot in the field often produce methane, a greenhouse gas even more potent than carbon dioxide. Burying energy-rich wastes in a landfill is like burying petroleum instead of using it [2].

13. Disadvantages

Today's bioelectricity plants have generation costs higher than those of fossil fuel generation. Biomass fuels contain less concentrated energy [2], are less economic to transport over long distances, and require more preparation and handling than fossil fuels. These factors contribute to higher costs.

Other challenges to the increasing use of bioelectricity include competition with natural gas, the need to develop high-yield, low-input energy-crop farming practices, and the need for more research to improve biopower technologies.

14. Conclusions

The Stirling generator using biogas as a fuel gives electricity to the rural people 4 hours per day and 7 days a week. The generator worked very fine and required very little maintenance. This type of external combustion generator has the unique advantage of not being corroded by the H_2S contained in the biogas as the combustion is take place in the external burner and heat is transferred to the cylinder by heat exchanger. The working fluid in the cylinder is helium. The pressure of helium varies from 480 – 600 psi depending on the temperature in side the cylinder. The output of the generator was DC but it can be modified to give AC electricity. A family size bio-digester is enough to run this type of small-scale generator and thereby helping a lot in rural electrification and reducing pressure on the grid power.

The support of bioelectricity is fundamental in developing sustainable, low-carbon energy options for the long-term. Bioelectricity will tend to be more expensive than other renewable electricity sources, such as wind, but is likely to compete with future costs of electricity from fossil sources, in particular if environmental costs are accounted for [2]. The costs of bioelectricity could be lower in applications where other products such as heat and transport fuels are generated [5]. Such applications need to be encouraged. Also, the decentralized nature of bioelectricity could result in savings and benefits with regard to electricity transmission and distribution. These need to be accounted for through proper electricity sector regulation. Finally, there is need for greater dialogue. Governments need to establish biomass industry and stakeholder forums to identify the opportunities and needs of the industry, define targets related to research, development, demonstration and implementation.

To maximize likely benefits and minimize potential impacts, the following guidelines should be followed:

• Biopower schemes need to be subject to rigorous and transparent environmental impact assessments.

• Good agricultural and forestry practices must be adopted, suitable for local conditions.

• There should be no conversion of natural forests or High Conservation Value habitats involved in raw material production or supply.

• Biomass growing practices must protect and enhance soil fertility.

• Water use should be assessed throughout the production and conversion chain, with particular emphasis on avoiding damage to watersheds.

• On the production side, best available conversion technologies should be used to minimize emissions.

• Ash quality from conversion processes should be monitored and where possible nutrient-rich ash should be recycled back to the land.

The bioelectricity has several environmental advantages, including: substituting fossil fuel use with a CO_2-neutral alternative; reducing emissions of other atmospheric pollutants, such as sulphur; protecting soil and watersheds; increasing or maintaining biodiversity: and reducing fire risk in forestry. These benefits provide a powerful argument for accelerating the introduction of bioelectricity in virtually all developed and developing countries.

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In his short professional life Mr. Chowdhury did a good number of job in both local and multinational organizations. He worked as a maintenance engineer in Bengal Plastic Ind. Ltd. then service engineer in Tetra Pak and project engineer in Emergence Energy Inc. He also was a faculty member in the department of mechanical engineering of Dhaka University of Engineering and Technology (DUET), Gazipur, Bangladesh. Currently he is working as an Assistant Manager in National Load Despatch Center (NLDC) project of Power Grid Company of Bangladesh (PGCB) Ltd., an enterprise of Bangladesh Power Development Board (BPDB). Mr. Chowdhury published a no. of papers both conference and journal in different innovative topics.
Mr. Chowdhury is a member of BSME (Bangladesh Society of Mechanical Engineers) and IEB (Institution of Engineers, Bangladesh). He received a no. of scholarships for his excellent academic feat.

Kurt Kornbluth, a self-proclaimed ”gear head”, holds the distinction of being the only student at Ypsilanti High School ever receive an A in both physics and auto mechanics. Interested in automotive design, he attended Engineering school at Michigan State University then landed a job with General Motors at their high-speed test track. After about a year Kurt left the security of GM to travel and be a street musician. In between trips he worked as an auto mechanic, drove a cab, and did carpentry to make ends meet. Kurt moved to California in 1991 and attended San Francisco State (SFSU) where he earned a master’s degree in Mechanical Engineering with an environmental emphasis. During this time he worked as an energy analyst for the SFSU Industrial Assessment Center, specializing in energy conservation and pollution reduction. While at SFSU Kurt met Ralf Hotchkiss, the founder of Whirlwind Wheelchair International (WWI), an American NGO that sets up appropriate technology Wheelchair production in developing countries. Kurt and Ralf hit it off and Kurt soon found himself working for WWI as a trainer, designer, and jig builder. This was the start of more than 10 years of traveling and working in Africa, Central and South America, and the Middle East. In 1996 he was awarded the Paralyzed Veterans of America student design award for his Master’s thesis project “A High Stability Omni-Wheelchair”. In 2002 Kurt was awarded a NSF IGERT fellowship to pursue a PhD in Mechanical Engineering at UC Davis. He is has been working with DEKA Research and Development on his thesis

"Rural Power Generation with a Biogas-Fueled Stirling Engine", focusing on Bangladesh and Zambia. Kurt still is involved with WWI and DEKA but is now a staff member at the Massachusetts Institute of Technology (MIT) "International Development Initiative". During the school year he introduces MIT students to appropriate technology in developing countries as an instructor for D-Lab.