Techno Economic Assessment for Setting up a Viable Biogas Plant at a Local Landfill in South Africa

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Abstract

The potential to economically run a biogas plant for the generation of fuel for use by the local buses was investigated. Various organic waste with varying total solids (TS) and organic loading were investigated for bio methane generated under mesophilic conditions. The first plant had a capacity of 10 tons per day and TS loading of 11% and 15%. Assuming 20 years of operation, after investing R 10 848 338, a breakeven point of 9.9 years with an internal rate of return of 8.3% was achieved for TS loading of 15% with 85% base. Whereas, when a 50 tons per day plant was investigated for a TS loading of 11% and 15%, a breakeven point of 6.4 years was achieved with an internal rate of return of 14.3% at an organic base of 85%. From the assessment, it is economical to set up a 50 tons per day plant and the biogas produced has potential to power more than 10 local buses. This can be further increased if the organic loading in the bio digester is increased to 25% TS content.

Keywords: Biogas, economic assessment, organic waste, internal rate of return

1. Introduction

Biogas is increasingly becoming a source of renewable energy in developing countries. Biogas which is mainly composed of methane (CH_4) is made from organic waste through anaerobic digestion (Gebrezgabher, 2009). Although the production of biogas from organic municipal waste is topical, the economic assessment of adopting the technology still needs to be done especially when applying in a local context. The purpose of an economic assessment is to study the various possible economically viable routes involved in the production of the biogas (Murphy et al., 2003; Chacon, 2004; Khan et al., 2014). This study therefore focused on the potential to economically generate biogas that can be used in the local buses as a source of fuel among other uses as shown in Figure 1.

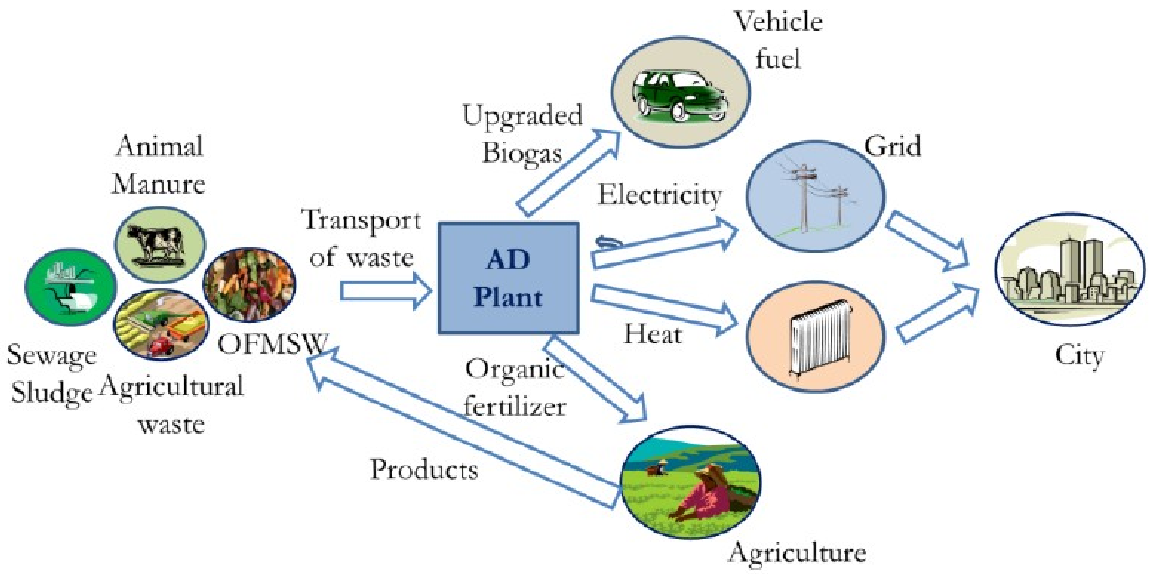

Figure 1: Various uses of biogas (Williams, 2005)

2. Materials and Methods

2.1 Materials

Municipal waste was obtained from a local landfill and was characterised for the organic waste composition. The municipal waste was then shredded for uniform distribution of the waste easy of digestion. Figure 2 shows some of the organic waste from the local landfill.

Figure 2: Municipal waste used for biogas digestion

2.2 Methods

The physical characteristics of the municipal waste were measured using standard methods. The crucible with the sample was placed into a preheated oven to 105 °C and the volatiles allowed to evaporate for 1 hour.

TS determination: Total solids (TS) were calculated as the ratio between the amount of dried sample and the initial amount of wet sample.

VS determination: The volatile solids (VS) were determined by expressing TS as a percentage of wet samples. The crucible was taken out of oven and allowed to cool to room temperature in a desiccators. Crucible was weighed and value recorded. Crucible was transferred into a furnace pre-heated to 550 °C. After 2 hours, dish is taken out of furnace and allowed to cool to room temperature in desiccators. Crucible was weighed and value recorded.

A standard economic analysis was conducted for the potential to either have a 10 tons/day plant or a 50 tons/day plant and the correct plant size chosen based on viability. A 20 years life plan for the plants was considered.

3. Results and Discussion

3.1 Waste Characterization

The waste characterization was conducted at the University of Johannesburg (UJ) laboratories. For the local landfill, mixed waste comprised of mainly garden waste and vegetable waste. The percentage total solid (TS%) for mixed and garden waste was 27.3 and 29.3%, with moisture content of 72.7% and 70.7% respectively. The mixed waste had carbon to nitrogen (C/N) ratio of 14.6 while garden waste had 10.1. At Johannesburg Municipality, the volatile solid expressed as a percentage of TS (VS% of TS) ranged from 40% for cucumbers to 96% for potatoes. The average VS% for the sampled fruit and vegetable was 78% with a median of 82%. About 99% of substrates from Johannesburg Municipality had C/N ratio within the optimal ratio of 10-30 (Moriarty, 2013), with about 1% of substrates being above the optimal. The highest C/N ratio of about 36.6% and 46.4% was observed in beans and pea respectively.

3.2 Biochemical Methane Potential Analysis

The biochemical methane potential (BMP) analysis was used to assess the degree of degradability of the sampled organic waste. The analysis was conducted at the UJ Process Energy and Environmental Technology Station using automated methane potential test system equipment. Initial result indicated a BMP of 310 m^3 CH_4/ton VS with average CH_4 concentration of 59.5 %, this gives about 510 m^3 biogas/ton VS.

3.3 Description for Process Flow Diagram for Biogas Production

The waste is sorted from the different station and the organic matter classified. The organic municipal waste is then crushed for size reduction and effective anaerobic digestion. Digestion is allowed to take place under mesophilic conditions. Two digesters of $60m^3$ and $420m^3$ are required for optimal biogas production from the waste. The generated biogas is then sent for upgrading. Mesophilic conditions of 35°C are maintained using heat from combined heat and power generation (CHP). Bio solids (digestate) are removed for further processing as bio fertilizers. The detailed block flow diagram is shown in Figure 3.

3.3.1 Economic potential to run a 10 tons/day biogas plant

The first objective was to provide sufficient bio fuel to run a metro bus per day. For that purpose, a plant capacity of 10 ton/day was considered capable of meeting the need of a metro bus per day at the worst driving conditions and engine performance. Based on interview with the General Manager of the technical division of Johannesburg Metropolitan Bus Services Limited, 100 L of diesel is required per day/bus which is equivalent to about 107 Nm^3 of bio methane per day. To account for vehicle engine efficiency, driving pattern and other losses, an estimated 1.3 load factor was considered as fuel requirement for the metro buses. Based on the waste characterisation, the BMP analysis, need to provide sufficient fuel and to improve economics of scale, a 10 ton/day plant capacity was considered with a bio methane potential of 254 Nm^3/day. In order to achieve this, two digesters of $60m^3$ and $420m^3$, are required amongst other plant peripherals. Based on detailed literature guided search, the whole plant cost (biogas production and upgrading) is estimated at $638 138 (R 10 848 338) at an exchange rate of 1USD to 17 ZAR (Simeon, 2009; Garcia, 2014).

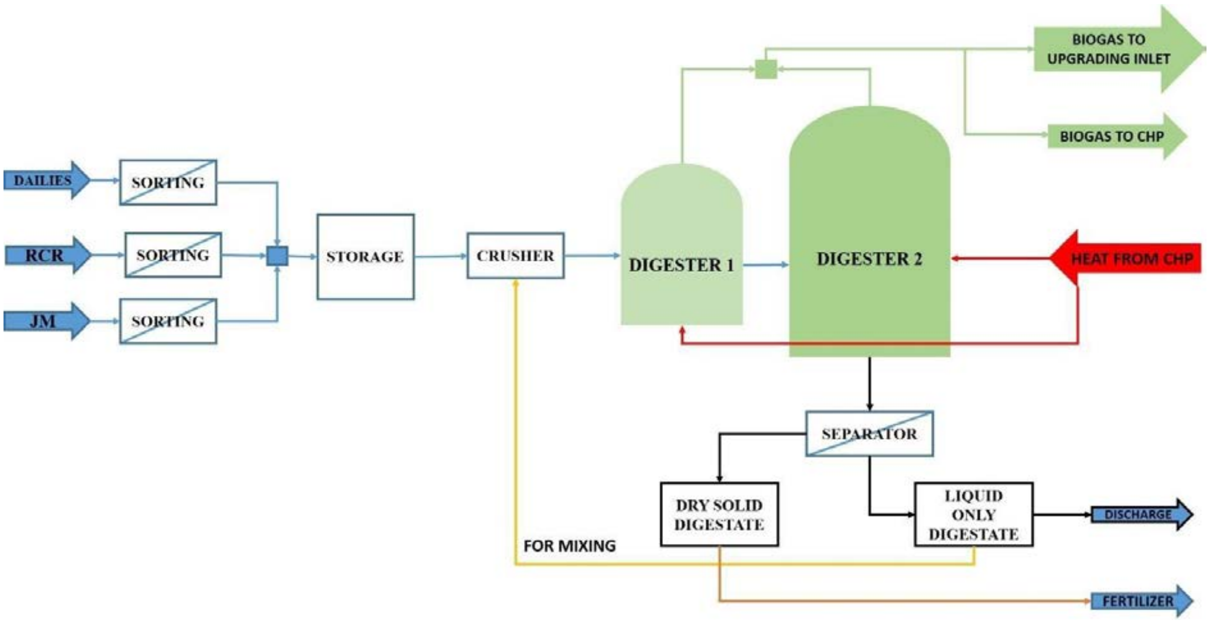

Figure 3: Biogas generation process flow diagram

Table 1: Economic assessment for setting a 10 tons/day biogas plant

	TS = 11%			TS =		
VS	**78% (base case)**	**80% (Medium case)**	**85% (High case)**	**78% (base case)**	**80% (Medium case)**	**85% (High case)**
Biogas yield (m^3/year)	159 716	163 812	174 050	217 795	223 380	237 341
Net biogas (m^3/year)	137 576	141 672	151 910	195 656	201 240	215 201
Bio methane (m^3/year)	79 794	82 170	88 108	113 480	116 719	124 817
Diesel (L/year)	75 006	77 240	82 821	106 671	109 716	117 328
Metro bus fuelled/year (100%)	1	1	2	2	2	2
Metro bus fuelled/year (30-70%)	5	5	5	7	7	8
Annual sales income before tax	1 112 085	1 133 543	1 187 185	1 416 382	1 445 642	1 518 790
Break even (years)	14.6	14.2	13.4	10.7	10.2	9.9
Break even (years) 5% discount	Nil	Nil	Nil	15.6	14.8	13.6
IRR (%)	3.6	3.9	4.5	7.2	7.5	8.3

3.4 Economic Assessment

The 10 ton/day plant will produce 75 006 litres/year of diesel equivalent bio methane at base substrate parameters of 11% TS and 78% VS of TS (see Table 1). Total income before tax is estimated at R1 112086. However, at a 5% discounting rate, the 10 ton/day plant will not break even during the 20 years assumed project life span. Increasing the substrate characteristics to 15% TS and 85% VS, the plant will produce 117 328 litres/year of diesel equivalent bio methane sufficient to fuel two metro buses and will break even in the 13th year after start up as presented in Table 1 with an internal rate of return (IRR) of 8.3% .

3.4.1 Economic potential to run a 50 tons/day biogas plant

Due to the long duration of payback period for the 10 ton/day plant, the second option investigated the economic viability of diverting all JM fruit and vegetable waste and the organic fraction into an anaerobic digester. A 50 ton/day plant capacity was therefore investigated. Capital expenditure (CAPEX) was estimated to be at R35 313 750 and annual operating expenditure at 3% CAPEX (R1 060 500) with 2.5% yearly escalation rate. At base conditions of 11% TS and 78% VS of TS, 161 365 litres/year of diesel equivalent of bio methane will be produced (see Table 2). This fuel is sufficient to fuel four (4) metro buses per year. At the base condition, the plant will break even in the 14th year after start-up. Increasing the TS to 15% and VS to 85%, which is practicable, 381 961 litres/year of diesel equivalent of bio methane will be produced as shown in Table 2. The payback period will be 8 years with an internal rate of return (IRR) of 14.3%.

If grass-residues are co-digested with JM fruit and vegetable waste, TS can be increased to 25%. At 85% VS, 831 617 litres/year of diesel equivalent bio methane can be produced. This is sufficient to fuel 20 metro buses per year.A break even of 4.4 years with an IRR of 26.0% is achievable as presented in Table 3.

Table 2: Economic assessment for setting a 50 tons/day biogas plant

TS = 11%						
VS	**78% (base case)**	**80% (Medium case)**	**85% (High case)**	**78% (base case)**	**80% (Medium case)**	**85% (High case)**
Biogas yield (m^3/year)	832 517	853 864	907 231	1 135	1 164 360	1 237
Net biogas	295 973	317 320	370 687	598 707	627 816	700
Bio methane (m^3/year)	171 664	202 450	214 998	347 250	364 133	406
Diesel (L/year)	161 365	173 002	202 098	326 415	342 285	381
Metro bus fuelled/year (100%)	4	4	5	8	8	9
Metro bus fuelled/year (30-	10	10	12	2 0	21	23
Annual sales income before tax	5,092,7 15	5,204,558	5,484,164	6,678,849	6,831,362	7,212 ,643
Break even (years)	10	9.7	9	7	6.9	6.4
Break even (years) @ 5% discount.	14.6	13.8	12.6	9	8.6	8
IRR (%)	7.7	8.0	9.0	1	13.1	14.3

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Table 3: Bio methane potential for a 50 tons/day with TS of 25%

Description	Values
Biogas yield (m^3/year)	2 061 888
CHP Self usage (m^3/year)	536 544
Net biogas (m^3/year)	1 525 344
Energy value (MJ)	34 777 832
Energy MJ/kg/LPG	709 752
Bio methane (m^3/year)	884 669
Mass of bio methane	973 169
Diesel (L/year)	831 617
Metro bus fuelled/year (100%)	20
Metro bus fuelled/year on fuel mix (30-70%)	51
Annual sales income before tax (ZAR)	11 533 842
Break even (years)	3.9
Break even (years) @ 5% discount.	4.4
IRR (%)	26.0

4. Social Impact Assessment

Several benefits are obtained from the usage of biogas as a source of energy. These include the fact that the biogas is a renewable source of energy since waste is generated on a daily basis. Furthermore, the amount of greenhouse gases emitted to the environment is reduced due to the reduced amount of carbon dioxide s and methane emitted to the environment from the rotting of the carbon dioxide. Digestion of waste to biogas also reduces the amount of waste that ends up at landfills, increasing the lifespan of the landfills. The living conditions of people are also improved by having a clean and sanitary environment.

5. Conclusion

The waste quantification conducted indicated that all organic wastes discharged at a local landfill are available for energy recovery as they are presently being covered with top soil to degenerate. If all organic wastes are converted into bio methane, about 100 Metro buses can be fuelled. The 20% is a conservative estimate of the theoretically calculated 157, representing 29%, metro buses that can be fuelled. There is a low likelihood for return on investment for a 10 ton/day plant and high potential for return on investment for a 50 ton/day plant especially when co-digested with grass residues. A 50 ton/day which holds higher return on investment with a shorter payback period is highly recommended for investment.

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Biography

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