A Management option for Landfill Leachate

Introduction and Background

The problem of leachate production, volume, movement, storage and final discharge are of concern to landfill operations since their inception. Leachate management at the Cooks sanitary landfill is no exception. Some of the activities of the NSWMA are geared to the challenges of handling this "commodity", and to seek solutions that would mitigate its impact upon its immediate environment.

Leachate is the liquid generated from moisture associated with materials within the landfill cell, after field capacity has been reached. Its production may be thought of as landfill percolation.

Although the rate of production of leachate over a given year is influenced by the volume of rainfall percolation through the landfill, among other factors, it is quite likely that there would be a significant volume build-up if provision is not made for its continual removal. A myriad of volatile organic molecules concentrate in the solution. By virtue of their complexity, their resistance to biodegradation, and their quantities, some of the accumulated molecules render the ever concentrating leachate solution highly toxic.

The actual composition of leachate solution may vary greatly within individual landfills over time (Tchobanoglous *et al* 1993) as well as among different landfills largely because of the chemical composition of the waste itself, but also because of the amount of precipitation in the area and other site-specific conditions. Some of the different chemicals contained in leachate have been categorised as Volatile Organic Compounds, Metals/metal ions, Synthetic Organic Compounds, Other.
(Tables 1-3 below)

Table1.1: Composition of leachate: dissolved substances

Composition	Contents	Sources	examples
simple molecules	Volatile organic compounds (***vocs)*** Hydrocarbon***s***	*.household.* *.Commercial* *.industrial …* *products /activities*	Vinyl chloride, benzene, Tetrachloroethylene trichloroethylene (tces),
Toxic Metals	eg. Heavy Metals	chemically active metal deposits (landfill conditions)	Cadmium, copper, Iron, manganese, Lead

Table 1.2: Composition of leachate: Persistent (colloidal) compounds.

Characterization	Contents	Sources	examples
complex chemicals	Synthetic organic chemicals, ***socs****.*	1. Agricultural activities: 2. Power-line transformers	- Herbicides - Pesticies - fungicides - Pcps, Pcbs

Table 1.3: Composition of leachate

Characterization	Contents	Sources	examples
Other	Myriads of Acohols, acids and esters	1.Biodegradation of organic substances, mostly natural. 2. Solvents, and household products	Methanol; ethanol ; also Propanol, butanol, phenol

When leachate is generated within methanogenic landfills, methane gas often remains dissolved in the liquid. If no pre-treatment is undertaken, which itself removes this methane, then the gas must be "stripped" (removed) from the leachate before discharge. (www.leachate.co.uk/html/treatment.html) Where and when the gas is allowed to accumulate, there is always the potential for spontaneous combustion at the right moment, hence the incidences of spontaneous landfill fires. (Author's notes). The potential of landfill leachate lies in the copious quantities of energy molecules that can be degraded anaerobically to yield significant quantities of methane fuel, of which there is much value (Tebutt, 1992).

Comparative processes

Sources of renewable energy are steadily gaining importance because of the uncertainty that exists regarding the future cost of crude oil. Leading the way is the potential of geothermal energy and also methane gas, the latter being obtainable from fermentative degradation of suitable materials in biogas plants.

Millions of cubic metres of methane in the form of swamp gas or biogas are produced every year by the decomposition of organic matter, both animal and vegetable. Biogas is almost identical to the natural harnessed from petroleum wells and used by many for various domestic purposes, including space heating and cooking. In the past, however, biogas had been treated as a dangerous by-product that must be removed as quickly as possible, instead of being harnessed for any useful purposes. It is only really in very recent times that environmental scientists have started to view biogas in an entirely different light, as a new source of power for the future. (www.habmigern2003.info/biogas/methane-digester.html). One of these pioneers is Ram Bux Singh, now the director of the Gobar Gas Research Station in Aiitmal, northern India where the world centre of biogas research is to be found today.

During the second half of the 1900s, the science of Bio-energy, which includes bio-methanisation (biogas), biomass gasification, and ethanol production from biomass, had been an on-going development in the developing world. This technology features wide-ranging fermentation of materials, clear mechanism, simple process and suitable extension of the resources (Hall and Hobson 1988).
The Chinese were first to have created the comprehensive utilisation of biogas in practice, and the range of application had developed from lighting and cooking to productive fields. This not only brought the power of biogas technology to the productive arena, but also established its active role in agricultural production and by-product development, treatment of residue and creation of social wealth, thereby adding to the diversity of economic development (Hall and Hobson 1988). A number of usages for biogas have been identified in the area of energy utilisation. These are summarised in table 2.

Table 2. Methods of Biogas Energy Utilisation (Hall and Hobson, 1988)

Method	*Applications*
Direct use of Biogas as heat energy	Cooking fuel, processing and preparation of food products.
Indirect use as heat energy	Increasing (or controlling) temperature to germinate rice seedlings; raise silkworms; hatch poultry eggs and to warm greenhouses in winter.
For Light energy	Providing Lighting (biogas lamps) in areas without electricity, raising silkworms and increasing silk production
For gasoline and diesel oil saving; electricity generation	Biogas replaces gasoline and diesel fuel by at least 70% of the fuel requirements for some agricultural machines.

Importance and Implications for Leachate digestion

There have been significant and increasing trends in the digestion of municipal waste material for the purpose of energy production. Included in this area is the anaerobic digestion of septage, and also landfill leachate (Chiu-Yue Lin et al, 1998). This paper will attempt to conceptualize an alternative energy focus beginning with leachate degradation while extending the process to incorporate the treatment of sewerage and sewage effluents.

While leachate digestion proposes an option for its management, such a process could lead the way for the processing of liquid waste. An advantage here would be the increase of biogas volumes and of methane concentration. **Degradation processes** are naturally on-going within a disposal site, but virtually hundreds of thousands of volumes of Methane go untapped and unchecked, off into the atmosphere! It is important for us to recognize that "when the methane goes, potentially, a significant amount of money also goes!"

Thus, the necessary efforts should be made to harvest and harness this important energy source to the benefit of Caribbean states. Landfill constituents provide suitable raw material for the production of methane gas and since the technology of Landfill Gas Recovery is currently available it allows for the exploitation of energy from wastes and residues (Benemann 2000). Through this technology there is the practical advantage of mitigating greenhouse gas emissions, while exploiting opportunities for selection and use of non-fossil-fuels (Manna *et al* 1998).

Work Done on Leachate Digestion.

1. According to Stronach *et al*, (1986), the volume of methane produced is affected by the dominant composition of the waste stream. While complete carbohydrate breakdown yields a 50:50 gas mixture of methane (CH_4) and carbon dioxide (CO_2), lipids and proteins respectively yield more than and less than this ratio.

2. In work to characterize leachate (Obbard *et al*, 1999), data for European landfill leachates compared to municipal waste-water data confirm that landfill leachates are considerably stronger in decomposable organic material than municipal wastewater. In addition, the characteristics of an acetogenic leachate from Hong Kong showed an average BOD and COD concentrations of 40,000 and 25,000 mg/l respectively (Table 3). (Obbard *et al*, 1999).

Table 3: Comparison of Leachate with Municipal Wastewater

Parameter	Acetogenic Leachate (Europe)	Methanogenic Leachate (Europe)	Sewage (Europe)	Leachate (Hong Kong)
BOD (mg/l)	10,000	200	200	40,000
COD (mg/l)	20,000	2,000	500	25,000

The data in table 3 suggests that a large quantity of soluble and partially soluble organic materials that end up within a dumpsite or landfill will subsequently become an integral part of landfill effluent. Furthermore ,with such high BOD and COD values in leachate, it is highly likely that methanogenic and acetoclastic organisms (bacteria that produce acetates and methane, respectively) find suitably available substrates in abundance in order to carry out their specific activity.

3. Timur, and Ozturk (1999) evaluated the Anaerobic “treatability” of municipal landfill leachate using lab-scale anaerobic sequencing batch reactors (ASBR) at 35°C. Their studies were conducted at a wide-range of volumetric and specific loading rates, by varying hydraulic retention times (HRT) (10-15 days) and influent wastewater COD's (3800-15900 mg l^{-1}). The COD removal efficiencies were in the range of 64-85% depending on volumetric and specific loading rates applied. The maximum volumetric methane production rate (VMPR) of 1.851 CH_4 l^{-1} d^{-1} was achieved, at the volumetric loading rate of 9.4 g COD l^{-1} d^{-1}. The specific methane production rates in terms of COD were about 1.06 g CH_4-COD per gram of volatile suspended solids per day (g VSS^{-1} d^{-1}) in the reactor. The results had shown that about 83% of the COD removed during treatment was converted to methane.

4. Work done by Lin C–Y (1991) evaluated the treatment of landfill leachate by mesophillic bacteria (optimizing at 35°C). It was shown that the anaerobic process was suitable for high strength organic wastewater largely because of the added advantage of its energy product recovery potential. In spite of this, a disadvantage was that a long digestion time was required; also, mesophillic organisms required some energy input.

5. Work done at the University of Bradford, England, (Author’s notes, 2001) investigated the degradation of Synthetic Landfill leachate using a laboratory scale anaerobic baffle reactor. Synthetic leachate was prepared to represent freshly formed leachate (solution A), mature leachate (solution B) and old leachate (solution C), Table 4.

Table 4: Organic composition of Synthetic LeachateSolutions A, B and C (per 30 litres).

Organic Material	Solution A mg/l	Solution B mg/l	Solution C mg/l
Glucose	999.00	1999.80	3999.60
Acetic acid	4.50	9.00	18.00
Sodium acetate	6.15	12.30	24.60
Glycine	1.53	3.06	6.12
Pyrogallol	0.50	1.009	2.018
COD values mg/l	1011.68	2025.17	4050.34

The following information were obtained among the results: (because of time constraints, more information was available from the digestion of solution B)

Table 5: Results from Digestion of Synthetic Leachate Solution A

Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Gas volume, cm^3	3000	3750	3750	3000	4000	3750	2000	2750	3500	250	-	3250	3250	4250	3500
Temp. C	18	18	18	18	18	18	18	18	18	20	20	20	21	22	22
pH (a)	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.9
COD_{in} (mg/l)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**1012**
COD_{out} (mg/l)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**1244**

Source: Data obtained from experimental investigation: Author’s notes

Table 6: Data for Digestion of Synthetic Leachate Solution B

Days	Gas volume cm^3	Temp 0C	pH influent	pH effluent	COD_{in} mg/l	COD_{out} mg/l	%COD reduction	COD removed per day (g)	Methane Gas yield (l/g)
1	3000	22	7.9	-					
2	-	22	7.9	-					
3	-	22	7.9	-					
4	-	22	7.3	-					
5	-	22	7.8	7.0					
6	2000	22	7.1	7.0					
7	-	22	7.1	7.0					
8	1500	22	7.1	7.0					
9	1500	20	7.1	7.0	2285	1049	54.09	17.80	**0.04**
10	1250	20	8.1	7.0	2700	1000	62.96	24.48	**0.03**
11	-	20	7.8	-			-		
12	-	20	7.7	6.7			-		
13	500	18	7.7	6.8	2500	800	68.00	24.48	**0.01**
14	250	20	7.1	6.7			-		
15	250	18	7.7	6.8	2330	900	61.37	20.59	**0.01**
16	250	22	-	-			-		
17	-	22	-	-			-		
18	-	22	-	-			-		

Table 6 continued

Days	Gas volume cm^3	Temp 0C	pH influent	pH effluent	COD_{in} mg/l	COD_{out} mg/l	%COD reduction	COD removed per day (g)	Methane Gas yield (l/g)
19	-	22	7.9	n			#N/A		
20	4000	22	8.2	7.0	1860	1000	46.24	12.38	**0.16**
21	7000	22	8.1	6.7			#N/A		
22	6000	20	8.3	6.8	2500	1366	45.36	16.33	**0.18**
23	5750	21	7.9	6.7			#N/A		
24	5500	20	8	6.8			#N/A		
25	5250	20	7.8	6.8	2400	1460	39.17	13.54	**0.19**
26	4000	20	7.9	6.7			#N/A		
27	4000	20	7.7	7.2	2200	900	59.09	18.72	**0.11**
28	4500	21	7.8	6.7			#N/A	0	
29	3500	#N/A	#N/A	#N/A			#N/A	0	
30	4500	#N/A	#N/A	#N/A			#N/A	0	
31	4100	#N/A	#N/A	#N/A			#N/A	0	
32	2500	#N/A	#N/A	#N/A			#N/A	0	
33	2500	20	7.1	7.0	2500	400	84.00	30.24	**0.04**
34	4000	20	8.4	6.7	2600	1700	34.62	12.96	**0.15**

Source: Author’s notes: Experimental investigation with synthetic leachate

Summary of the outcome:

The pattern of gas production for both solutions B and C (Table 6) showed generally, that a high gas volume accompanied a high COD reduction. This was the trend observed during the steady period between days 20 to 27 for solution B. The gas production as determined at the times of COD determination table 6. ranged from 0.01 to 0.19 litres for solution B; the maximum amount of methane possible, in theory, is expected to be 0.35 litres per gram (Terzis, 2001).

The actual total methane production was calculated, taking the methane lost in the effluent as negligible. Although the gas-liquid system follows Henry's law (Yu and Anderson 1995), the methane fraction of the gas occupied 50% of the actual total volume produced (Terzis, 2001, personal communication). Methane yield was calculated by use of the formula (Terzis 2001).

$$CH_4\,\text{yield} = \frac{\text{Volume of } CH_4 \text{ produced daily (litres)}}{\text{COD removed daily (grams)}}$$

5. The work undertaken by ENVIROS Consulting has seen the commissioning of a scientifically designed methane stripping plant for Greater Manchester Waste Disposal Authority, to design parameters resulting from detailed. This plant, for which the installation contract was undertaken by Hytech was designed to "strip" up to 1,000m^3 /day of leachate at a cost of approximately 0.4 UKP/m^3 (power and maintenance).

Figure 1. Methane stripping plant for Greater Manchester Waste Disposal Authority

In related work by the said company, a second leachate processing plant was commissioned in Marianhill, Durban, South Africa, 1998. The Mariannhill landfill currently generates approximately 30 cubic metres of leachate each day, with the potential to discharge up to a sustained flow of 50 cubic metres per day. Mariannhill serves the disposal requirements of the Western reaches of the Thekwini Municipal Area, and is expected to be in operation for another 14 years. The **leachate treatability trials** were conducted, in a joint research and development programme between Enviros and Durban, from October 1998.

6. No investigation on the degradation of Landfill leachate on Antigua had ever been carried out. Therefore, there is no empirical data available.

Benefits and Environmental Concerns

This document proposes the exploiting of landfill leachate, expressly for the production of energy. Some of the advantages to be derived include the following:

1. A project of this undertaking has room for much research and development; the pursuit of such knowledge and information would require an upgrade to existing monitoring equipment, an increase in the depth of scientific analytical details, and would impact the education process.

2. Technological changes involving methane has also lead to the commissioning of 'Gober gas' for hybrid vehicles and a reduction in the consumption of "regular" fossil fuel for the internal combustion engines and Power generating plants in India. (www.environmentalengineering.in/biogas/.html)

3. After purification, methane gas can be bottled into cylinders. In fact, such a venture has the potential for becoming a useful alternative to the well established LPG gas cylinder.

4. Biogas is the fuel used in many electrical generation stations in China. There are about 400 biogas power stations, with a total capacity of 5,800 HP. 800 biogas electric stations, with a total capacity of 7,800 kw, provide electricity to over 17,000 households. The Chinese have solid experience in running diesel and gasoline engines with biogas. (www.EvangelosTrade.com). The transfer of this technology ought to be explored.

5. A significant reduction of direct emission of landfill gases into the atmosphere is welcomed. Methane has as much as six times the deleterious effects of carbon dioxide upon the global warming phenomenon. Thus, stripping leachate of methane has this added advantage.

The chemistry of this process is quite simple, but is very profound:

$$\underset{\text{Methane}}{CH_4} \underset{}{\overset{\text{Sunlight/ photo-dissociation}}{\rightleftharpoons}} \underset{\text{methyl free-radical}}{CH_3{*}} + \underset{\text{Hydrogen free-radical}}{H{*}}$$

$$3O_2 \overset{\text{(Normally in atmosphere)}}{\rightleftharpoons} 2O_3 \quad \text{(oxygen – ozone equilibrium in atmosphere)}$$

Atmospheric disruption

$$2CH_3^* + O_3 \longrightarrow (CH_3)_2O + O_2$$

free radical attacks ozone (difficult to reverse) → dimethyl oxide + free oxygen

6. No tremendous amount of direct energy input is required for leachate digestion because the degradation process is biotechnologically mediated.

7. Neither production nor utilization involve the release of smoke nor ash into the environment

8. It can be easily moved from its source to its point of consumption.

The Production Process

The process of Biogas production follows primarily a simple recognizable pattern of Biodegradation. As shown in fig.1, complex organic substances are converted into simple organic substances, which in turn are converted into organic acids and then methane, accompanied by other gases.

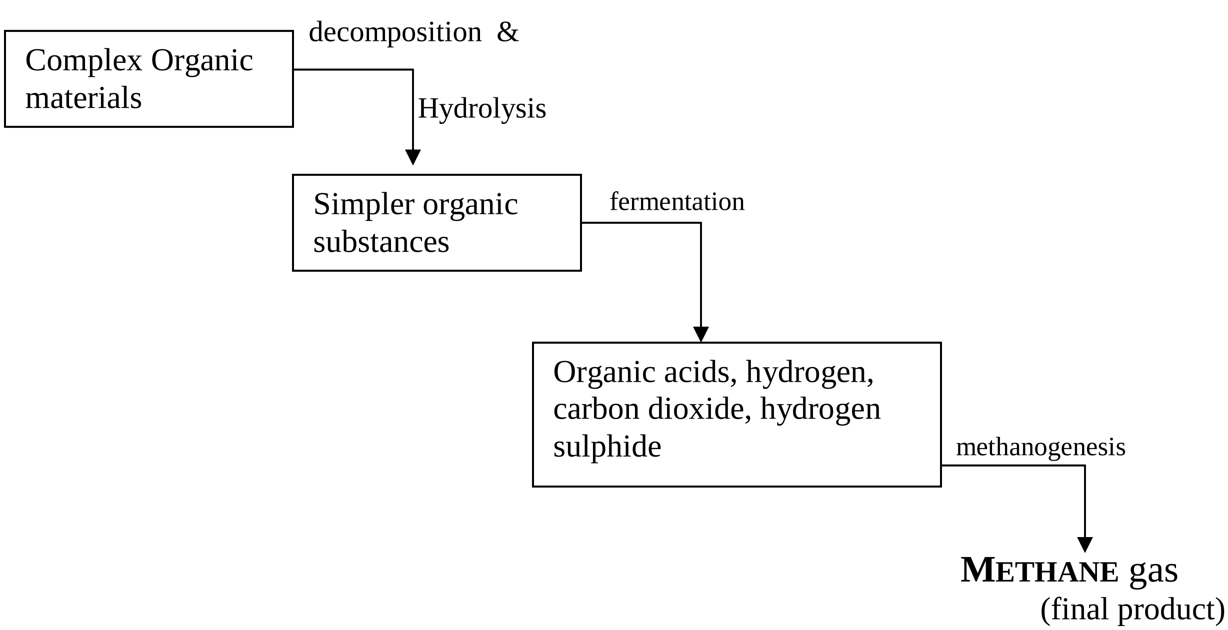

Fig.2 **Steps in the Biodegradation of Organic Wastes**

Modular Design for a typical process

A Multi-Purpose, Continuous Flow System that uses tanks (usually tall vertical cylindrical vessels) that contain membranes impregnated with bacteria through which the leachate is forced to flow is appropriate. The environment inside the tank in the vicinity of the membranes is designed to promote bacterial growth (to feed off the contaminants in the leachate).

Such a basic system is capable of processing many different waste streams simply by choosing the bacteria to match the constituents of the stream. For treating landfill leachates, this approach requires a relatively high initial capital investment which is expected to be offset by the returns from the use of methane. The cost of operation lies in electricity consumption, bacteria cost and manpower. However, this approach provides a high degree of process control. One advantage is the possibility of varying the conditions in the same tank or in tanks placed in series. Another advantage is that these bio-digesters are designed to turn high strength wastes (food waste, green waste and a variety of animal products and waste) into methane gas. This approach is also considered for processing the "high quality" component of the raw garbage that is now being dumped in the landfill, and is a very practical means of extracting useful energy molecules from materials now being discarded (Figure 4). (The approach of processing garbage might reduce the amount of leachate that must be processed but it will never eliminate the need for leachate processing).

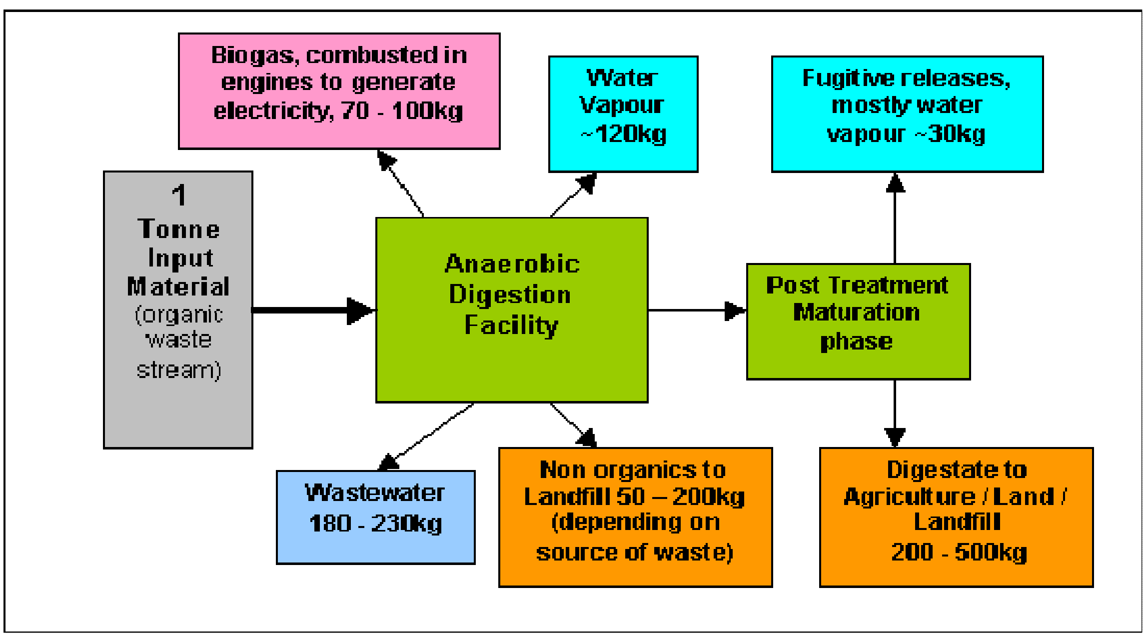

Figure 4. Schematic of Inputs and Outputs of a typical Anaerobic Digestion process

Typical capacity: 5,000 tpa - 60,000 tpa (modular facilities, larger capacity can be achieved by a number of digesters on one site).

Source: www.anaerobic-digestion.com

Economic Importance

Energy values and equivalents of Biogas:
With its usually high percentage of methane, landfill gas is likely to have a very high energy value of approximately 56,000 Joules per mole. This ranks very high compared to other commonly used fuels. (Table 7)

Table 7. Energy values for select Fuels

Material Fuel	Energy value KJ/mol	Energy value Per kilogram (KJ/kg)
Methane	56,000	3,500,000
Propane	67,000	1,595,240
petrol	42,000	368,421
Wood	35,000	216,050

Source: Fergusson & Hart (1986)

Production equivalents.

According to *Weise & Konig, one cubic metre, m^3, of biogas contains about six kilowatt hours of available energy and is equivalent to about 0.6 litres of fuel oil, in terms of its average calorific value. This allows for a theoretical quantificatication of the commodity*
[*source: Weise, Jurgen and Ralf Konig, Monitoring of Digesters in biogas plants, www.hach-lange .com*]

A number of models are available for calculating the electrical energy obtainable (theoretically) from the "feed" into a Biogas plant. One of these is briefly described as follows:

1. Based on 1000Kg of decomposable material, and also considering a 50:50 gas mixture, an equivalent formula shows:

1000Kg of decomposable material produce 40m^3 of gas

40m^3 of 50: 50 gas mixture contain 20m^3 of methane

20m^3 methane gas ≡ 17 Kg (given)

Also, given that:
1m^3 can provide 6Kwh of energy,
Then, 20m^3 can potentially provide 180kwh

Thus, 1000kg of digestible material ≡ 180kwh (of energy)
or, 1Ton, 2000kg " " ≡ 360 kwh

(www.environmentalengineering.in/Biogas.htm)

2. Another model developed by Electrigaz, [(**info@electrigaz.com**) Ontario Canada], was designed to monitor the wastes produced by farm animals, and to quantify the volume of methane generated by animal waste digestion annually. This model suggested that1m^3 of biogas can generate 1.7kWh of electrical energy.

3. Information extract taken from the Remade Scotland Report: An Introduction to the Digestion of Organic Wastes, (Monnet, F. 2003) indicated that a large centralized AD plant processing 100,000 tons per annum of cow slurry, would be expected to produce very approximately:

- 3,110 MWh/y or 31.1 kWh/tonne of electricity
- 5,710 MWh/y or 57.1 kWh/tonne of heat

(Note: Figures should be regarded as indicative values only).

In each of these projections, the feeder material used was slurry from farm holdings. Information to this effect from solely landfill leachate has not yet been sighted by the author.

Future Challenges and recommendations

As for any venture, a number of challenges exist for this focus on leachate. Some of the leading concerns include the following:

1. Attempts should be made to carry out a complete chemical analysis and characterization of the leachate at the civic amenities site so that its potential for sustaining a small to medium scale degradation may be assessed. The carbon and nitrogen compositions and also the BOD and COD values would have to be determined regularly. Also, the daily flow rate must be stabilized.

2. Leachate from well managed modern landfills ought to be assessed for the presence of COD concentrations of at least 6,000 mg/l; this concentration must be sustainable for more than 2 or 3 years from each landfill cell if a methane extracting venture is to be successful to repay start-up capital costs.

3. In addition to leachate characterization, the air around the sanitary landfill cell and the old landfill site ought to be regularly sampled in order to determine the nature and quantity of all gases present. This allows for an assessment of the volume of methane that is lost naturally to atmosphere.

4. A determination of the quality and quantity of the gas reserves within the old landfill site should also be carried out. Any leachate from this location would represent mature to old leachate which is likely to have a higher COD than leachate from an active sanitary landfill.

5. While focusing on the leachate, the possibility of incorporating other liquid waste effluents into the digestion process should also be explored. This has implications for establishing a significant treatment for liquid waste, particularly because of the fuel production potential.

6. The merging of gas from degradation processes from all areas of the civic amenities site ought to be explored.

7. Leachate processing potentially brings avenues for the development of local, technical experiences and expertise with educational and employment possibilitiy. Moreover, the necessary arrangements must be made for the transfer of technology from countries where it has already been developed. This venture ought to be considered in the quest for waste to energy in Antigua.

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