LANDFILL GAS GENERATION & RECOVERY OPTIMIZING THE RESOURCE, UTILIZATION TECHNOLOGIES & GLOBAL WARMING CONTRIBUTIONS

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1.0 LANDFILL GAS - BACKGROUND

The trends and technologies utilized in landfill disposal of solid wastes have undergone extensive improvements over the last several decades, such that effective control of the landfill residuals is attainable. Management of the leachate and landfill gases is critical to ensure acceptable performance of a landfill. The concerns related to the off-site migration of landfill gas include both the near-site and global implications. Near-site concerns relate to consideration of odors and human and environmental exposure risks. The global implications relate to concerns about the global warming potential associated with landfill gas (LFG) emissions.

Recognition that LFG emissions represent a major source of anthropogenic methane emissions to the atmosphere has increased attention towards methods to control and reduce LFG emissions. To put this in perspective, LFG accounts for approximately 26 percent of Canada's total methane releases to the atmosphere. Hence, the control of LFG represents an important opportunity for countries to strive towards meeting its international commitments in accord with the Kyoto Protocol.

Methane is recognized as a greenhouse gas (GHG) with a global warming potential that is 21 times greater than carbon dioxide by weight. LFG is composed of roughly equal proportions of methane and carbon dioxide. Thus, control of methane releases from landfills represents a very important consideration in terms of decreasing the anthropogenic sources of GHG emissions from Canada. Combusting and utilizing the energy content of the methane will accomplish two important goals:

(i) the role of LFG as a GHG is decreased to a fraction of its original value;

(ii) otherwise-combusted fossil fuels are not required which will result in a further net reduction of anthropogenic GHG emissions.

The utilization of LFG as an energy source is proven technology. There is relatively widespread utilization of LFG in about 20 countries worldwide. The largest number of projects using LFG are in the U.S.A., Germany, UK, Sweden and Canada. To date there are more than 500 LFG recovery schemes in operation specifically for energy recovery/utilization. A primary barrier to LFG utilization is access to local markets since the transportability of the LFG often introduces a significant detrimental impact on the economics of a LFG utilization project. Of interest in this paper is the potential for improving the economics of recovery of the LFG by optimizing the field conditions to improve collection efficiency opportunities of LFG.

This paper examines alternatives for improving the methane recovery potential for a landfill to make investment in the recovery of the LFG more attractive. The key focus is enhancement of the production and collection of LFG during the time when recovery is of interest. For some projects this may mean increasing the rate of generation, but for others it may mean controlling and/or retarding the rate of generation in a portion of the site or all of a site to ensure better collection system efficiencies to improve the viability of a project. The end result would be enhanced LFG capture and utilization over the life cycle of a site which will improve the collection opportunities and subsequently the recovery opportunities for LFG utilization.

1.1 PRINCIPLES OF DECOMPOSITION

Decomposition of organic matter and the subsequent formation of methane is indigenous to nature. Anaerobic metabolism may take place whenever the ingress of oxygen is stopped completely or limited to the extent that microbes remove the oxygen. For the production of methane to occur, however, there must be growth of methanogenic bacteria which requires highly specific environmental conditions. Figure 1 shows the decomposition by-products in a conventional landfill.

The quantity of gas which will be produced from landfills can be estimated by various methodologies which utilize a number of principles and approximations including the basic stoichiometry of the conversion process, assumed conversion efficiencies, approximations of the overall biodegradability of typical refuse, or total organic content of composite refuse. The two primary variables related to the prediction of LFG production are:

(i) the total volume of LFG that will be produced for a given mass of refuse (referred to as total or ultimate yield); and,

(ii) the time over which the LFG will be produced.

Enhancement of gas generation can be made by controlling such factors as waste composition, pH, moisture content, nutrient availability, alkalinity, presence of inhibitory substances, and site design including cover material and waste depth. The opportunity exists to predict changes to total gas production and gas production rates during specified periods of time (e.g. during the active recovery period of LFG for energy utilization).

Figure 2 shows the average chemical profile of LFG throughout the years.

1.2 FACTORS INFLUENCING DECOMPOSITION

The potential exists to adjust the ambient environment in the landfill to effect some control over the production of gas.

Waste Composition -Waste comprises a mixed mass of material whose composition varies according to source and with time. Waste degradation is a dynamic and changing process, with each new degradation stage being dependent on the creation of a suitable environment by the preceding stage. Waste components which contain significant biodegradable fractions include food waste, waste from animals, garden waste, and paper and cardboard.

Methanogenesis conditions do not form immediately after refuse is placed in a landfill. Months or years may pass before the proper environmental conditions (primarily oxygen-free) are established and the required microbial populations developed. Development of these conditions for methanogenesis can, at least in part, be optimized and controlled by design and operational aspects of a landfill.

Degradable organics total sixty-six percent of the waste stream in accord with the waste composition in 1992 for Canada (Environment Canada) and have been subdivided as follows:

Waste Stream Characterization

Waste Stream	***Mean Percentage (% by weight)***
food	12.6
garden waste	18.7
paper	35.0
plastics/rubber	3.5
textiles	2.4
wood	2.7
metal	8.0
glass and ceramics	10.4
ash and soil (other)	7.7

- **Influences of Changes in the Waste Composition -** The nature of waste deposited in landfills has important implications for the subsequent degradation processes and gas production potential. As organics are removed from the waste stream, the quantities of methane being generated are naturally reduced. For example, the recycling of paper would decrease LFG production. Hence the opportunity for LFG recovery for utilization will be directly affected and must be considered when assessing the merits and viability of a project.
- **Waste Pre-processing -** With recognition of the solid waste management problem and the potential impact of improper management on the environment, alternative methods for management of refuse have been explored (e.g. shredding, and additives).
- **Temperature and Insulating Effect of Refuse -** Temperature conditions within a landfill influence the type of bacteria that are predominant, and consequently the rate of gas production.
- **Moisture and Field Capacity -** Moisture content is the most important parameter in refuse decomposition and gas production.
- **pH -** Generation of methane in landfills is greatest when neutral pH conditions exist.
- **Inhibiting Effects of Oxygen Intrusion Through the Landfill Cover -** The presence of oxygen will result in aerobic microbial degradation. Therefore, in terms of trying to

maximize methane production during the recovery period of the LFG, procedures which minimize oxygen introduction into the landfill are desirable.

- **Density Implications -** As the proportion of glass, ceramics, ashes, grit and metals increases in the waste, so will the density of the refuse.
- **Implications for Design versus Operating Variables -** Gas recovery potential is greatly influenced by the design and operation variables at a landfill. Waste disposal procedures such as the degree of compaction, degree of capping, and moisture content of the refuse will affect LFG emissions.

The sequence and method of filling the site can affect the type of LFG collection field that is selected. Horizontal collection trenches are effective at allowing earlier recovery of LFG emissions since they allow collection during the active site filling period. Vertical collection wells are generally constructed after landfills are capped.

2.O LANDFILL GAS - OPTIMIZING THE RESOURCE

CONSIDERATIONS OF ADVANCED SITE MANAGEMENT OPTIONS

The intent of this section is to characterize the impact of one or more of the features outlined in section 1, to enhance the production of LFG during periods of recovery of LFG. Utilization of various site management options will make it possible to manage the way that the site produces methane, and to review any ramifications in terms of expenditures.

To undertake gas extraction, a zone of negative pressure gradient (suction) must be developed to collect the gas using mechanical systems. There are a number of variables which affect the size of the capture zone established in the landfill due to an induced gradient at a well or trench. These include the following:

- practical limitations exist on the suction or vacuum that may be applied;
- horizontal and vertical transmissivity (flux of LFG) of the wastes results in greater transmissivity horizontally;
- depths of static leachate levels in the waste; and
- daily, intermediate, and final cover soil and flexible membranes influence gas and liquid transmissivity.

2.1 EVALUATION OF POTENTIAL LFG DEVELOPMENT SCENARIOS

To quantify the implications of the various individual landfill design and operating scenarios, a spreadsheet model was employed. A generic landfill design was used as the basis for comparison. The generic landfill shape used was a fulstrum pyramid. The generic landfill design parameters are detailed in the following table.

Landfill Design Parameters Utilized in Scenario Evaluations

Maximum height of landfill	20 m
Landfill sideslopes	4Horizontal:1Vertical
Total time of landfilling operations	approximately 15 years
Refuse tipping rates	50,000 tonnes/yr 200,000 tonnes/yr
Average refuse density (at site closure)	1 tonne/m^3
Average daily cover density	1.7 tonnes/m^3
Daily cover volume	20% of total refuse volume
Average methane content of LFG	50% by volume

Total LFG Yield from Refuse - Several annual tonnage rates were explored to test the sensitivity of the various LFG development options in response to the tipping rates and total site capacities. The minimum number of years for feasible LFG recovery system operation was assumed to be approximately 20 years.

Greenhouse Gas Equivalents - A numerical calculation of the GHG equivalents associated with the various LFG scenarios is utilized for a comparison between the individual scenarios. Hence, the evaluation counts carbon dioxide as a straight percentage value, while the methane counts as equivalent percent to carbon dioxide (i.e. 21 times as large).

Revenue Timestream of Assessment - The revenue timestream of assessment quantifies the timestream of costs and benefits arising from the various scenarios. There are a number of elements within the cost characterization and the benefits associated with utilization of the LFG which are recovered. Assuming the landfill will be operating on a regular basis for the disposal of wastes, the cost calculations described herein determine the incremental costs associated with LFG utilization.

Scenarios of Assessment - Analyses of LFG recovery opportunities are completed to facilitate assessment of the effects of individual site management activities on the viability of LFG utilization. The base case scenario involves utilization of a single landfill cell and vertical LFG collection system. The following table outlines the various features and scenarios that were assessed.

Scenario	Single Landfill Cell	Multiple Landfill Cells	Vertical LFG Wells	Horizontal LFG Trenches	Low Permeable Cover	Leachate Recycle	pH Buffering	Nutrient Supplement	Leachate Heating	Waste Shredding	Waste Baling	Recycling Program	Organic Waste Diversion
I	√		√										
II	√			√									
III		√	√										
IV		√		√									
V		√		√	√								
VI		√		√	√	√	√	√					
VII		√		√	√				√				
VIII		√		√	√					√			
IX		√		√	√						√		
X		√		√	√							√	
XI		√		√	√								√

2.2 ENERGY UTILIZATION OPTION INVOLVING DIRECT BURNING

Assessment 1 - Number of Cells and Vertical Versus Horizontal Gas Collection Systems for Direct Burning

This analysis assumes that the LFG is collected and burned at a cement kiln. The gas has a market value associated with the heat content. The cement kiln has the capacity to utilize all of the gas recovered/pumped during the recovery period. The LFG is assumed to displace natural gas which would otherwise be utilized.

Landfill Gas Utilization for Different Scenarios for Direct Burning

Scenario		% LFG Lost Before Recovery	% LFG Recovered	% LFG Lost (flared during recovery)	% LFG Lost (flared after recovery)	GHG Equivalents	Years of Operation
I	Vert./1 Cell	36	39	9.9	16	866	20
II	Horiz./1 Cell	6.7	63	16	15	483	31
III	Vert./4 Cells	13	57	15	15	565	32
IV	Horiz./4 Cells	4.5	65	17	15	454	31
V	IV/Tight Cap	4.5	72	8	15	454	31
VI	V/Recycle	4.5	79	8	9	454	21
VII	V/Recycle & Heat	4.5	82	8	6	454	17
VIII	V/Shredding	5.5	73	8	13	471	28
IX	V/Baling	3.8	70	8	18	445	34
X	V/Recycle (50% reduction)	2.1	64	10	10	422	45
XI	V/Diversion (39% organics)	2.1	64	10	10	422	45

Assessment 2 – Economic Evaluation of Direct Burning

Utilization of the LFG at a nearby cement kiln involves displacement of natural gas which would otherwise be utilized. If a price of 0.12 $/m^3 is utilized as the cost-avoided by not purchasing natural gas, the revenue time-stream for LFG recovery is equivalent to the energy value of the LFG.

Results of the economic analysis for direct burning of LFG under different scenarios are summarized below.

Summary of Economic Evaluation of Direct Burning at Cement Kiln

Scenario		Present Worth of Revenue(10M $)	Present Worth of Costs (10M $)(1)	Net Present Worth (10M $)
I	Vert./1 Cell	3.2	2.4	0.8
II	Horiz./1 Cell	3.9	2.6	1.3
III	Vert./4 Cells	3.5	2.4	1.1
IV	Horiz./4 Cells	4.1	2.8	1.3
V	IV/ Tight Cap	4.7	2.8	1.9
VI	V/Recycle	6.2	3.3	2.9
VII	V/Recycle & Heat	6.8	3.8	3.0
VIII	V/Shredding	5.1	3.8	1.3
IX	V/Baling	4.2	3.8	0.4
X	V/Recycle (50% Reduct.)	3.0	2.8	0.2
XI	V/Diversion (39% Organics)	1.8	2.8	-1.0

Notes: (1) Allowance for $1,000,000 is for capital and O & M of shredding/baling equipment. Processing costs of refuse not included in cost characterization

2.3 ENERGY UTILIZATION OPTION INVOLVING GENERATION OF ELECTRICITY

The generation of electricity using LFG as the feedstock represents another potential use. For the generation of electricity, there are times during which an excess of LFG is recovered which would have to be flared since the generating units have a maximum net unit capacity and are available only in integer quantities (1,2,3…etc.). As an example, LFG generation beyond the capabilities of use of 2 generating units but insufficient to warrant utilization of a third generating unit, means that the excess recovered LFG must be flared to minimize the global warming potential.

Landfill Gas Utilization for Different Scenarios for Electricity Generation

Scenario		% LFG Lost Before Recovery	% LFG Recovered	% LFG Lost During Recovery	% LFG Lost After Recovery	GHG Equivalents
I	Vert./1 Cell	36	33	15	16	866
II	Horiz./1 Cell	6.7	55	23	15	482
III	Vert./4 Cells	13	33	39	15	565
IV	Horiz./4 Cells	4.5	64	11	15	454
V	IV/Tight Cap	4.5	52	29	15	454
VI	V/Recycle	4.5	62	24	9	454
VII	V/Recycle & Heat	4.5	77	13	6	454
VIII	V/Shredding	5.5	50	32	13	467
IX	V/Baling	3.8	37	41	18	445
X	V/Recycle (50% reduction)	2.1	38	50	10	422
XI	V/Diversion (39% organics)	2.1	31	57	10	422

Without including greenhouse gas credits, the most important observation for the electrical power generation option for LFG utilization is that only scenario VII would have a positive net present worth, with all of the other scenarios losing money, for a 50,000 tonnes/yr. tipping rate (small site size) (note that the economics include the cost of the LFG collection system which may be a regulatory or site specific requirement). Considering this same analysis performed for a higher refuse tipping rate of 200,000 tonnes/yr, the amount of LFG lost (as a percentage of the overall quantity of LFG generated) is substantially less than at a lower tipping rate of 50,000 tonnes/yr., resulting in improved economies of scale.

2.4 SUMMARY OF ALTERNATIVES

A number of conclusions can be derived from analyses of the various scenarios. These include:

- horizontal collection wells allow earlier recovery for LFG and result in significant reduction in GHG emissions in comparison with vertical collection wells;
- development of a landfill as a series of cells has some merit in terms of improving recovery opportunities of GHG and in the economics of recovery options, but the differences aren't that large if horizontal wells are utilized as the collection mechanism;
- attainment of field capacity and the recycling of leachate provides an opportunity for improving gas recovery potential at some sites by managing the gas generation rate in part/all of the site;
- preprocessing the refuse through shredding or baling, to the extent to which the LFG generation rate can be characterized with existing information, does not substantively improve the economics of LFG recovery and/or reduce GHG emissions;
- the implication of the recycling of organic wastes and/or waste diversion is to somewhat reduce the viability of recovering the LFG for its energy value; and
- larger sites have a substantively greater potential for development of their LFG resource because of the economies of scale.

2.5 RECOMMENDED PRACTICES FOR OPTIMIZING LANDFILL GAS CONTROLS

A combination of advanced site management practices have the potential to significantly improve opportunities for LFG collection/utilization. Used in an effective site management plan, the following benefits can result:

- reduced contaminating lifespan (i.e. GHG emissions);
- improved safety and health considerations;
- improved economics;
- coordination with other landfill control systems; and
- satisfying current/future governmental regulations.

3.0 TECHNOLOGIES FOR UTILIZATION OF LANDFILL GAS

Various technologies exist for the utilization of landfill gas (LFG). The alternative that is best suited for a specific site is dependent upon a number of factors including:

- Projected landfill gas availability;
- Presence and location of suitable markets;
- Market price for end products;

- Environmental and regulatory factors; and
- Economics of utilization

Due to the low heating value of raw LFG (approximately 20000 Kjoules/m^3), the high moisture content and trace amounts of impurities present in the gas, facilities must be specifically designed or modified to use LFG. The presence of moisture in the system may cause problems related to condensation build-up. The impurities, in combination with moisture, may cause corrosion of the equipment.

The opportunities for utilization of LFG are directly dependent on the degree to which the LFG is processed and this, in part, is a function of the economics of the application. The three general levels of processing for LFG include:

i) minimal processing to produce a low grade fuel for heating. Minimal processing typically involves a condensate removal chamber as part of the LFG collection system to reduce the amount of moisture in the gas stream;

ii) primary processing to produce a medium grade fuel. Additional gas treatment devices are used to extract more moisture (with contaminants) and finer particulate matter. The process typically involves compression and refrigeration of LFG and/or chemical treatment to remove moisture and heavy end hydrocarbons from the raw gas; and

iii) complete processing to produce a high grade fuel. This typically involves gas pretreatment, gas compression and enhanced gas treatment to remove impurities and separation of methane and carbon dioxide.

Figure 3 shows the different LFG utilization options.

IMPLICATIONS OF GREENHOUSE GAS CREDITS

Consider now a simple example to characterize the values of potential returns. It is emphasized that these are intended only as an indicator of potential economic returns and require a number of assumptions and simplifications to keep the example at a level that can be easily followed. The results of these scenarios are intended only as orders of magnitude.

(i) Value of Greenhouse Gas Credits for LFG Utilized

Assumption 1 - Greenhouse gas credits are available for all of the LFG that will be recovered in the collection system for the utilization scenario.

Assumption 2 – Assume a twenty-year horizon for LFG recovery. Assume that an initial LFG collection system is constructed in the year 2000 and maintained for the next 10 years to the year 2010. In the year 2010, an increment to the LFG collection system is constructed which allows capture of a portion of the LFG from wastes placed during the 2000 to 2010 period, in addition to the LFG collected by the system which was functioning during the period 2000 to 2010.

Assumption 3 – An LFG collection system can be designed that will collect 65% of the methane that is produced.

Assume the potential collection rates of LFG as follows:

For years 2000 to 2010, .65 (2200 cfm) = 1430 cfm (0,67 m^3/s)
For years 2010 to 2020, .65 (3500 cfm) = 2275 cfm (1,07 m^3/s)

Where: cfm = cubic feet per minute
Assumption 4 - For 1430 cfm (0,67 m^3/s), 50 percent of the LFG is methane, and the density of methane is 0.72 kg/m^3.
Therefore:
9030 tonnes per year of methane would be collected in the collection system, or:
21 (9030) = 189,000 tonnes per year of equivalent CO_2.
Assumption 5 - The value of the greenhouse gas credit is 1.68 $/tonne of CO_2, and no escalation in value occurs over the twenty-year period 2000 to 2010.
Assumption 6 – The real discount rate (net of inflation) is 6%.

Then:
The net present value (NPV) of Greenhouse Gas Credits for the period 2000 to 2010 is 2.36 million dollars, and:
The NPV of Greenhouse Gas Credits for the period 2010 to 2020 is 1.73 million dollars.
This is equivalent to a total of:
(2.36 + 1.73) million dollars (NPV) = 4.1 million dollars (NPV).

Summary - The net present value of the Greenhouse Gas Credit (for this hypothetical example) for the period 2000 to 2020 is 4.1 million dollars (NPV).

(ii) Value of the LFG for the purposes of generating electricity
Assumption 1 - Generators could be sized to utilize all of the LFG collected. This would allow the 1430 cfm to be utilized during the period 2000 to 2010 and 2275 cfm (1,07 m^3/s) to be utilized during the period 2010 to 2020.
Assumption 2 - Landfill gas has an energy value of 500 Btu/ft^3 (18623 KJ/m^3)
Assumption 3 - The generators operate at 35 percent efficiency.
Assumption 4 - The value of electricity generated is 3 cents/kWh (constant over the period 2000 to 2020).
The value of the electricity then is 11.6 x 10^5 $/year for the period 2000 to 2010 and:
18.5 x 10^5 $/year for the period 2010 to 2020.

This translates to a total NPV of 16.2 x 10^6 $ for electricity as a benefit.
However, the NPV of the costs for approximately 4 MW of electrical generating capacity for the period 2000 to 2010 corresponds to approximately 9.9 million dollars, and for approximately 6.4 MW of electrical generating capacity for the period 2010 to 2020 corresponds to approximately 8.9 million dollars. This translates to a total (NPV) cost of:

(8.9 + 9.9) million dollars (NPV) = 18.8 million dollars (NPV).
The total present value of net benefits thus would correspond to:
(16.2 - 18.8) million dollars (NPV) = - 2.6 million dollars (NPV).

In other words, this indicates that for electricity generation purposes alone, if 3 cents/kWh is obtained for the electricity, the investor would lose 2.6 million dollars (NPV).

It is noted that the combination of electricity value and the greenhouse gas credits, provides a net present value of:
(4.1 - 2.6) million dollars (NPV) = 1.5 million dollars (NPV).
Assumption 5 - Investors obtain 4 cents/kWh. The benefits for electricity generation purposes alone would obtain 21.6 million dollars, and the net present value of the benefits would correspond to:
(21.6 - 18.8) million dollars (NPV) = 2.8 million dollars (NPV).
The combination of electricity value and the greenhouse gas credits would result in the net present value corresponding to:

(4.1 + 2.8) million dollars (NPV) = 6.9 million dollars (NPV).
Summary - For the simple example, the present value of net benefits if the electricity is valued at 3 cents/kWh would mean the investors would lose money on the investment for electricity generation alone, although there is positive cash flow if the value of the greenhouse gas credits is included.

The present value of net benefits if electricity were valued at 4 cents/kwh would mean the investors would make 2.8 million dollars on the investment for electricity generation alone, and a total of 6.9 million dollars from the combination of electricity and greenhouse gas credits.

(iii) Value of Electricity for Utilization at a Local Cement Kiln
Assumption 1 - Assume the average natural gas price is 0.11 $\$/m^3$
Assumption 2 - Assume that value to be paid for LFG is at one-half of the value of the natural gas, for equivalent heat value
For delivery of LFG at the rate of 1430 cfm (0,67 m^3/s) for the period 2000 to 2010 and for 2275 cfm for the period 2010 to 2020, the net present value of payments for the LFG consumed, would correspond to 8.2 million dollars
Assumption 3 - Assume that the cost of construction of the pipeline involves 1 million dollars from the Vancouver Landfill to a local Cement kiln.
Assumption 4 - Assume the compressor costs 200,000 $ and there is a cost of 250,000 $ for modification of the intake to the cement kiln.
Assumption 5 - Assume the cost for electricity to run the pipeline corresponds to 200,000 $/year.

Then the net present value of costs for the delivery of the LFG to a local Cement kiln would correspond to 3.7 million dollars.

The present value of the net benefits for delivery of the LFG to a local Cement kiln would total:

(8.2 - 3.7) million dollars (NPV) = 4.5 million dollars (NPV).

Summary - For the simple example, the net benefit for utilization of the LFG at a local Cement kiln corresponds to 4.5 million dollars for the value of the fuel and 4.1 million dollars for the value of the Greenhouse Gas Credits.

4.0 SUMMARY

The collection and utilization of landfill gas can be economically viable, if the conditions for the landfill and for the utilization opportunity are good. In fact, in terms of greenhouse gas reductions, the combustion of landfill gas for capture of greenhouse credits is one of the most cost-effective means (on a dollars/tonne basis) available for reduction of global-warming gases.

The procurement of greenhouse gas credits, for the purposes of making the economics of landfill gas utilization scenario viable, can be extremely important in making the utilization scenario a viable economic undertaking.

A number of landfill design and operating practices have been examined to determine their effectiveness, in some cases in isolation and in some cases in combination, for increasing the generation and recovery potential of LFG. Improved economics of utilization were determined to be directly related to the quantity of refuse being delivered to the site, the organic content of the refuse, and the proximity of potential users of the LFG. The existence of a LFG user for direct burn (e.g. a cement kiln, a smelter gas oven, etc.) in near proximity has the greatest potential for making positive net revenues for recovery. This occurs because all of the LFG recovered can simply displace otherwise utilized fossil fuel. Alternatively, a higher value for the gas arising from the generation of electricity is feasible but the market for the electricity must be available. Nevertheless, assuming the conditions pertinent to a landfill site as utilized in the evaluations within this project are representative, the economics at a landfill site receiving approximately 50,000 tonnes/year are favourable if the opportunity exists for the direct burn scenario. The economics at a landfill site receiving greater than 50,000 tonnes/year can be favourable for both direct burning and electrical power/generation when a combination of the advanced site management scenarios are adopted. Finally, LFG utilization technologies are site specific and must be evaluated on a case by case basis.

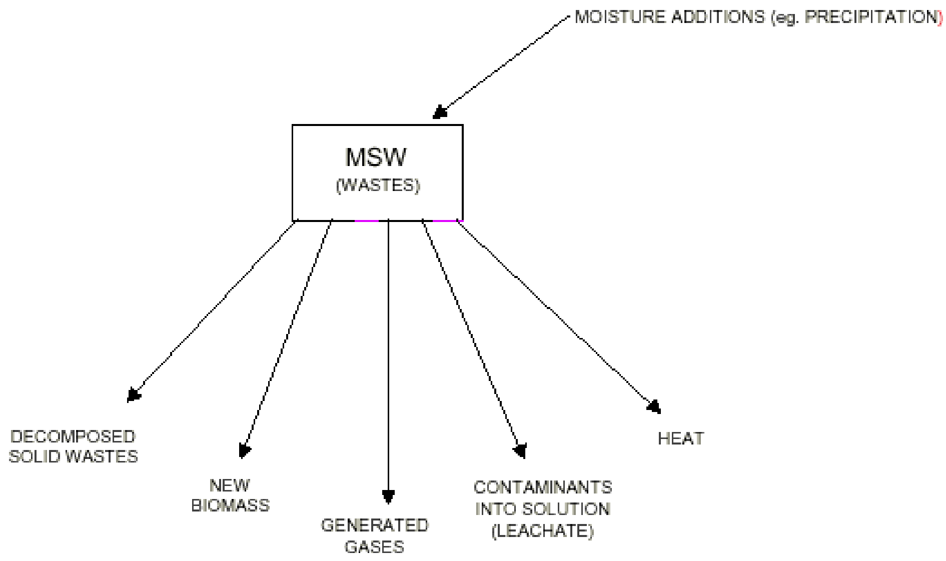

figure 1

BYPRODUCTS OF SOLID WASTE DECOMPOSITION

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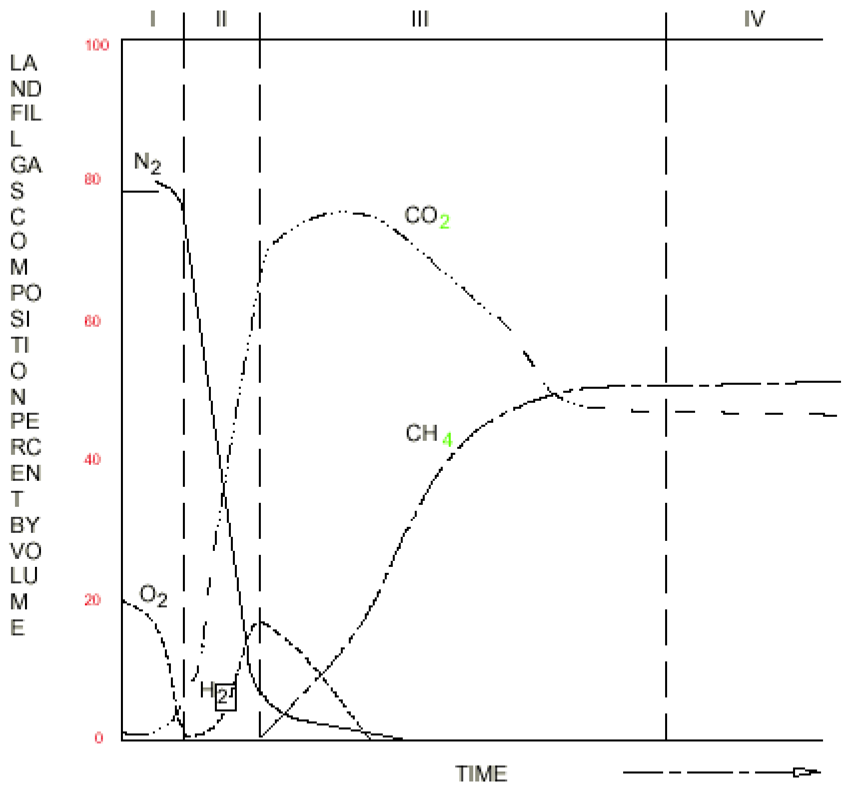
LANDFILL GAS PRODUCTION PATTERN

PHASES



PHASES	CONDITION
I	AEROBIC
II	ANOXIC
III	ANAEROBIC, NONMETHANOGENIC UNSTEADY
IV	ANAEROBIC, METHANOGENIC STEADY

figure 2

LANDFILL GAS PRODUCTION PATTERNS

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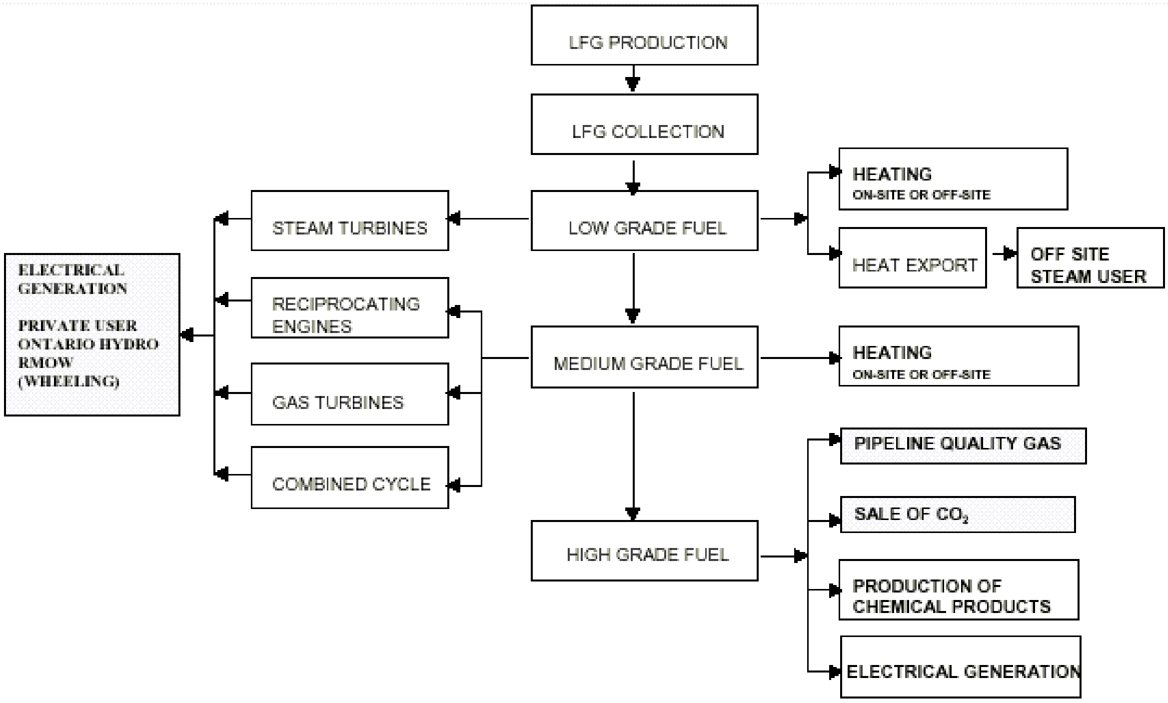

figure 3

LFG UTILIZATION OPTIONS

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