ECONOMIC FEASIBILITY OF LANDFILL GAS UTILIZATION

Highway 101 Landfill Site
Sackville, Nova Scotia

Prepared for:

Environment Canada

June 1997
Ref. No. 8809 (2)
This report printed on recycled paper.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

The following presents an evaluation of the economic feasibility of landfill gas (LFG) utilization at the Highway 101 Landfill Site (Site) in Sackville, Nova Scotia. The project is being undertaken jointly by the Halifax Regional Municipality, the Nova Scotia Department of the Environment, and Environment Canada. The report was prepared by Conestoga-Rovers & Associates (CRA) with background and site specific information provided by ADI Nolan Davis (ADI).

LFG is produced as a result of the decomposition of wastes placed in a landfill. LFG is composed primarily of methane (CH_4), carbon dioxide (CO_2), and trace levels of sulphur compounds and volatile organic compounds (VOCs). Methane and carbon dioxide are greenhouse gases. Methane is also potentially explosive. Sulphur compounds and VOC's contribute to odour and air quality concerns.

LFG is one of the largest anthropogenic organic sources of methane emissions to the atmosphere in Canada. It has been estimated that medium size landfills with waste capacity in the range of 2 -8 million tonnes such as the Highway 101 Site, are responsible for about 42 percent of Canadian methane emissions from LFG.

Uncontrolled release of LFG may result in environmental impacts and may also negatively affect public health and safety. Recovery and utilization of LFG can aid in addressing these concerns while reducing greenhouse gas emissions and making beneficial use of a resource that would otherwise be wasted.

LFG defies conventional approaches to categorization of resources as either renewable or non-renewable. LFG is renewable only in the sense that it is produced from wastes which are produced by society. Therefore, the source of LFG can be considered continuous, subject to the success of the population served by a landfill in waste diversion and reduction efforts. However, LFG should also be considered non-renewable in that, once a given volume of LFG is produced and escapes from a site, it may cause impacts and public hazards and it can no longer be recovered for use. Typically LFG is not stored within a landfill site, therefore its useful lifespan should be considered as finite.

There are numerous environmental and economic benefits associated with utilization of LFG. Production of energy from LFG provides a method of assisting environmental LFG controls, may provide financial benefits, and may also off-set the consumption of other less "environmentally friendly" fuels. When not utilized, LFG is a wasted resource that can be detrimental to the environment and the public. One approach to categorizing LFG is to consider it as an environmentally beneficial, perishable resource..

Given that there are well established technologies available for control of LFG, a LFG utilization program should be economically feasible to be undertaken.

The primary objectives of this study are to evaluate the feasibility of utilizing LFG produced at the Highway 101 Site and if feasible, to develop a program to implement LFG utilization.

Section 2 of this report contains a summary of background information regarding the Site. Section 3 presents an assessment of the Site's potential LFG production and a discussion of considerations relating to recovery of the LFG from the Site. Section 4 includes evaluation of technical options available for LFG utilization, an assessment of the feasibility of utilization and recommendations for implementation.

2.0 BACKGROUND INFORMATION

The Highway 101 Landfill Site is located in Sackville, Nova Scotia, approximately 14 kilometres northwest of Halifax. The Site is owned by the Province of Nova Scotia and is operated by the Halifax Regional Municipality.

The landfill is located on crown land in a lightly populated rural area. Nearby land uses consist of undeveloped land, single family dwellings, and a small quarry within a 500 metre radius of the Site. The Sackville River is approximately 100 metres south of the Site and flows from northwest to southeast.

The Site is underlain by medium to fine grained till that rests on a quartzite bedrock. Two drumlins containing very fine grained till were located within the Site boundary.

Landfilling at the Site began in November 1977 on an approved 120 hectare (ha) (300 acre) parcel of land. The "footprint" of the landfill itself is approximately 35 ha (88 acres). The landfill accepted refuse from Halifax, Dartmouth, Halifax County and Bedford. Table 2.1 presents the waste tonnage landfilled at the Site from 1978 to 1996. It was estimated that the quantity of waste landfilled in 1996 is the same as in 1995 bringing the total quantity of waste placed in the landfill to approximately 4 million tonnes. It was assumed that the waste composition is similar in nature to many municipal solid waste landfills and is made up of approximately 50 percent domestic waste and 50 percent industrial/commercial waste.

The approximate limit of refuse is shown on Figure 2.1. Two landfilled areas are located within the Site boundary. The larger portion of the landfill has been closed since 1994. In 1994 an extension to the original landfill was constructed to allow for an additional two years of filling. This extension is located in the southeast section of the Site and is partially on top of the older portion of the landfill. The 1994 landfill extension is lined with a geomembrane liner system. The extension to the Site was closed on December 31, 1996. The older portion of the Site contains approximately 84% (3,378,000 tonnes) of the total wastes in-place while the remaining 16% (665,000 tonnes) of the Site's wastes are in the landfill extension area.

Historically landfilling at the Site took place in 3 to 4 metre lifts which were covered with approximately 0.3 metres of daily cover soil. The daily cover soil used in the older portion of the Site is low permeability fine grained till from the drumlins and native till overburden. The daily cover soil used throughout the 1994 landfill extension is imported medium to coarse sand.

The average depth of the refuse is estimated at 12 metres, and the maximum depth of refuse is approximately 25 to 30 metres. The older portion of the Site is capped with a 1 metre thick layer of low permeability clayey soil with vegetation cover. The landfill extension area is not yet capped.

The older portion of the Site is known to have a significant leachate mound. Based on the leachate levels reported to CRA, a large portion of the refuse in the older portion of the Site is saturated. The groundwater table in the area is located near the ground surface. The local groundwater table elevation and flow pattern are assumed to be largely controlled by the proximity to the Sackville River.

A leachate collection system is in place at the Site to control leachate within the landfill. The leachate is collected from the older portion of the Site and from the extension area via toe drains. The collected leachate is processed by bio-treatment, activated sludge treatment, and wetland treatment, prior to discharge into the Sackville River.

The older portion of the Site is equipped with a landfill gas collection system comprised of vertical LFG collection wells, horizontal collection trenches, collection piping, blowers, and a flare. A more detailed discussion of the existing LFG collection system is included in Section 3.2.

3.0 LANDFILL GAS ASSESSMENT

To evaluate the feasibility of LFG utilization, it is necessary to determine the quantity and quality of the LFG that can reasonably be expected to be available for utilization. The following sub-sections assess the Site's LFG production potential and the capabilities and requirements for collection of the LFG that is produced.

The assessment of LFG production for the purpose of gauging the feasibility of utilization must present a conservative, realistic estimate of the LFG production expected. To ensure that these objectives are met, an analysis of the sensitivity of the LFG production estimate to variations in the input parameters is performed.

The assessment of the potential for recovery of the LFG that is produced includes an examination of the existing LFG collection system and development of recommendations for improvement and expansion of the system.

3.1 LANDFILL GAS PRODUCTION

The production of LFG is a result of the biological decomposition of solid waste placed in a landfill. This process takes place in stages. Within one or two years following initial placement of the waste in the Site, anaerobic methanogenic decomposition begins. This process generally continues until the organic matter has been decomposed. As the landfill ages, the rate of LFG production gradually decreases and the character of trace components in the gas may change somewhat.

The fundamental elements of LFG production estimates are the LFG yield, the unit LFG generation rate, and the LFG production rate. The landfill gas yield is the total volume of LFG produced per unit mass of refuse (i.e., m^3/kg or ft^3/lb.). The unit landfill gas generation rate is the volume of LFG generated per unit mass of refuse per unit of time (i.e., m^3/kg/yr. or ft^3/lb./yr.).

The LFG production rate is defined as the volume of LFG that is produced by the total quantity of refuse in-place in a site per unit of time (i.e., m^3/hr or ft^3/min.).

The yield and unit generation rate of LFG depend on several factors including:

- mass of refuse;
- age of refuse;
- moisture content;
- pH of moisture;
- organic content of the refuse;
- temperature within the refuse; and,
- quantity and quality of nutrients.

A number of models are available for estimating rates of production of LFG. Accepted industry standard models are generally first order kinetic models which rely on a number of basic assumptions regarding site specific conditions. These models are used to predict the variation of LFG generation rates with time for a typical unit mass of solid waste. This unit LFG generation rate curve is then applied to estimates/records of solid waste tonnages filled at the Site to produce an estimate of the Site's LFG production over time. Table 2.1 shows the quantities of solid waste landfilled at the Site.

3.1.1 Base Case LFG Production Model

The Scholl Canyon model, with defined default parameters, is accepted and recommended by the Ontario Ministry of Environment and Energy (Ontario MOEE), British Columbia Ministry of Environment, and the United States Environmental Protection Agency (USEPA) to evaluate LFG production rates for the purpose of assessing potential impacts. As this is the only large landfill in Nova Scotia, the Nova Scotia Department of the Environment has not yet developed a method of estimating LFG production for the Highway 101 Site. The Scholl Canyon model uses defined default parameters with Site landfilling history/projections to estimate LFG production. The

Ontario MOEE Scholl Canyon model will be used as the base case for estimating LFG production from the Site as this general approach has a wide acceptance.

The Scholl Canyon model uses the LFG generation rate decay constant (k), the methane generation potential (Lo), and records/projections of waste tonnages as input parameters to estimate LFG production over time. Typical values of k range from 0.02/year for dry sites to 0.07/year for wet sites. The methane generation potential depends on the waste composition and is directly related to the LFG yield which is highly variable from site to site. Production of LFG may continue for more than 50 years and can typically result in total yield of LFG in the range of 125 m^3/tonne up to 310 m^3/tonne (2 to 5 ft^3/lb.).

The Ontario MOEE and USEPA models express gas yield as the volume of methane produced per unit of waste. However, throughout this report gas volume is expressed in terms of total LFG assuming equal parts of methane (CH_4) and carbon dioxide (CO_2) unless specifically identified otherwise. This is done as LFG control systems are designed on the basis of their hydraulic capacity to handle the total amount of LFG collected.

The default input values for the Scholl Canyon model as defined by the Ontario MOEE (Lo_{CH4} = 125 m^3/tonne (2 ft^3/lb.), [Lo_{LFG} = 250 m^3/tonne (4 ft^3/lb.)], and k = 0.04/yr.) result in the unit LFG generation curve shown on Figure 3.1. Application of this unit generation curve to the Site filling schedule shown on Table 2.1 results in a peak rate of LFG production for the overall Site of approximately 3,300 m^3/hr (1,940 cubic feet per minute (cfm)). This peak value occurs approximately one year after Site closure in 1996 as shown on Figure 3.2 and labeled "MOEE Scholl Canyon (k=0.04/yr.)". Significant LFG generation is expected to continue past the year 2020.

3.1.2 Sensitivity Analysis

LFG models provide approximations of LFG production expected. To ensure that the range of variability of the input parameters is addressed, an analysis of the sensitivity of the LFG production calculations is conducted. The sensitivity analysis is carried out by varying input parameters within a reasonable range of values and by considering alternative modeling approaches.

The moisture content of the wastes is one of the primary factors influencing LFG production rates. It is known that large portions of the waste in the Site are saturated. To address this factor, the Scholl Canyon model was run with k=0.07/year instead of the default of k=0.04/year. Figure 3.1 shows the unit LFG generation curves. This simulates the faster rate of decomposition which would be expected from a wet site. When applied to the waste tonnage table, the Scholl Canyon model for wet wastes results in a peak rate of LFG production of 4,600 m^3/hr (2,700 cfm) occurring in approximately 1997. This scenario is shown on Figure 3.2 and labeled as "Wet Scholl Canyon (k=0.07/yr.)".

In another approach to assessing variability of the modeling results, alternative unit LFG generation curves were applied which are based on review of the Scholl Canyon model, consideration of the LFG production process, and observations of conditions at various landfills. The alternative unit LFG generation curves utilize the same LFG yield (250 m^3/tonne (4.0 ft^3/lb.)) as the Ontario MOEE Scholl Canyon Model but vary the rates of LFG generation differently. The alternative unit LFG generation curves are believed to be a realistic representation of overall LFG production reflecting the following:

- a gradual increase in the initial methanogenic production;
- a middle plateau phase which represents establishment of equilibrium conditions; and
- a somewhat more rapid decline in LFG production in the later years which represents the eventual consumption of the organic substrate.

Alternative unit LFG generation curves were developed for moderately and readily decomposable wastes. These alternative unit LFG generation curves were applied based on the assumption that equal proportions of the Site wastes are readily and moderately decomposable. This resulted in an overall peak LFG production rate for the Site of approximately 4,320 m^3/hr (2,540 cfm) occurring approximately 3 years after Site closure, as shown on Figure 3.2 and labeled as "Alternative Model".

To assess the effect that increased moisture content may have on LFG production using the alternative unit LFG generation curves, the peak unit generation rate was assumed to be 18.6 L/kg/yr. (0.30 ft^3/lb./yr.). This unit LFG generation curve corresponding to wet wastes was applied to the annual Site tonnage records. This results in a shorter duration of LFG production, with a more rapid decline as shown on Figure 3.1. This sensitivity run results in a peak rate of LFG production for the Site of approximately 5,750 m^3/hr (3,380 cfm) occurring approximately one year after Site closure, in 1997 as shown on Figure 3.2 and labeled as "Saturated Model".

3.1.3 Summary of LFG Production Modeling

Modeling of LFG production is typically best considered from a macroscopic point of view. It is recognized that LFG production calculations are at best, estimates and as such, actual values encountered may differ from those calculated. It is for this reason that the above methods of estimation define the possible ranges of LFG production as shown on Figure 3.2.

The following summarizes LFG production at the Site as estimated by the various modeling techniques described in Sections 3.1.1 and 3.1.2. The rates of LFG production for the year 2021 are shown to indicate the expected change in LFG production rates during the time frame in which LFG utilization may possibly be undertaken.

Model	*Peak Value (1997)*	*2021*
Ontario MOEE Scholl Canyon	3,300 m^3/hr (1,940 cfm)	1,260 m^3/hr (740 cfm)
Wet Scholl Canyon	4,610 m^3/hr (2,710 cfm)	860 m^3/hr (510 cfm)
Alternative Model	4,320 m^3/hr (2,540 cfm)	1,040 m^3/hr (610 cfm)
Saturated Model	5,750 m^3/hr (3,380 cfm)	590 m^3/hr (350 cfm)

3.2 LANDFILL GAS RECOVERY

A conservative assessment of the feasibility of LFG utilization must address the quantity of LFG which can reasonably be expected to be recovered from the Site. This is a function of both the Site's LFG production potential and the effectiveness of its LFG collection system. The following discusses the current status of LFG collection at the Site and presents recommendations to optimize LFG recovery.

The existing LFG collection system consists of the following components:

- 22 vertical gas collection wells located on the older portion of the Site;
- 7 horizontal gas collection trenches located below the impermeable liner separating the older portion of the landfill from the expansion area;
- gas collection header and lateral piping;
- a control plant containing:
  - condensate trap;
  - two blowers;
  - a flame arrestor; and
- a candle type flare.

Figure 3.3 shows the gas collection system layout for the Site. The LFG collection system is capable of collecting gas from the well field, and the horizontal collection trenches. Methane generated from a digester in the leachate treatment plant is disposed of using the LFG flare. The collection field currently in place collects gas from only a portion of the total landfilled area. It is understood that construction of lateral connections to allow collection of LFG from the leachate collection toe drain is currently underway. This includes installation of a number of condensate drainage traps on the LFG collection piping.

The extraction of LFG from the vertical wells began in 1994. The gas extraction wells are located in the centre of the older portion of the landfill and are installed approximately 15 to 20 metres deep into the refuse. A total of 22 vertical extraction wells are connected to a ring header via laterals. The wells at the Site are in a 750 mm diameter augured borehole, with 100 mm perforated PVC pipe in the center, gravel pack, and sealed with a 300 mm bentonite seal 2.0 metres below the ground surface. All wells are individually valved and the wellheads are housed in concrete chambers.

Horizontal collection trenches are located just below the geosynthetic separation layer, above the older refuse and under the south portion of the 1994 landfill extension. The trenches are spaced approximately 50 metres apart and are bedded in a continuous gravel blanket. The trench system and the vertical well system are connected to a common header.

The LFG extracted from the Site is transported to the control plant via a common header system. The control plant houses a condensate trap, two blowers and a flame arrestor. Free moisture is removed from the collected gas by the condensate trap prior to the blower. The gas is extracted via a 11.3 cubic metre per minute (m^3/min.) (400 cfm) blower. A second blower is available on standby in the plant. The collected LFG is flared with a 30.5 m^3/min. (1,077 cfm) capacity candle type flare.

It is CRA's understanding that in 1995 the LFG collection system extracted and flared approximately 144 m^3/hr (85 cfm)of LFG containing roughly 59 percent by volume methane gas. This LFG was collected from the vertical extraction wells and from the leachate treatment plant. The LFG collection system in the landfill extension area is not in operation due to the large intake of air that has been observed as a result of attempts to operate that portion of the system.

From the LFG production assessment in Section 3.1, it is estimated that between 3,075 m^3/hr (1,810 cfm) and 5,520 m^3/hr (3,250 cfm) of LFG was produced at the Site in 1995. This estimate is based on actual landfill tonnages received at the Site. This indicates that less than 5 percent of the total LFG produced at the Site was collected and flared. This is significantly less LFG than would reasonably be expected for this Site.

It is CRA's understanding that the soil used for daily cover was a fine grained low permeability silt till from the drumlins and the native till overburden. This method of landfilling has likely resulted in layering of the wastes as indicated by the historical problems with leachate seepage from the side slopes in the older portion of the Site.

A leachate collection system is in place at the Site, however leachate levels within the refuse in the older portion of the site remain elevated. A large portion of the waste mass in the older area of the site is saturated. In most of the older portion of the Site the leachate level is within 3 to 4 metres of the ground surface.

While saturation of landfill wastes enhances the rate of LFG production, the high leachate elevation creates challenges for collection of the LFG that is produced. The use of low permeability soil as daily cover in the older portion of the Site has stratified the wastes in this area. This has the effect of isolating the wastes in discrete pockets. The enhanced LFG production and the effect of the daily cover soils are demonstrated by the high gas pressures reported in the Site. This is causing LFG to vent from the surface of the older portion of the landfill in numerous locations despite the operation of the LFG collection system. This was evident on CRA's inspection of the Site and was particularly noticeable as bubbles escaping from wet or ponded areas on the landfill surface. This condition is not apparent in the landfill extension area.

From an inspection of the Site, and review of the drawings of the LFG collection system, the following potential problem areas were noted:

- most of the older portion of the site where the collection header is located is relatively flat or gently sloped;
- the wells are not equipped with flexible lateral connections;
- the wells are not equipped with telescoping slip sections; and
- existing condensate traps drain liquid back into the landfill.

These issues are of particular concern in addressing the long term performance of the LFG collection system to accommodate the extreme rates of differential settlement that are known to occur at landfill sites. To facilitate drainage of condensate from LFG collection piping, it is generally recommended that any collection piping located on refuse be sloped at a minimum of 5 percent and be equipped with drains at low spots. The ground surface in the area where the ring collection header is located does not meet this slope criteria. It is understood that the piping was placed generally following the surface contours. Over time and with differential settlement of the landfill, this would tend to cause low spots to form in the piping where liquid can accumulate. If sufficient liquid accumulates it can block the pipe preventing the flow of LFG. The monitoring data provided indicates areas where complete or partial blockage of the LFG collection piping may have already occurred.

It is generally a recommended practice that vertical LFG extraction wells on refuse be equipped with a length of flexible hose to connect the well head to the lateral piping as shown on Figure 3.4. This measure is also intended to address differential settlement of the landfill. The flexible hose is intended to allow the lateral pipe and vertical well riser to settle independently of each other to some extent. This can reduce the potential for damage to well laterals.

Telescoping slip sections (see Figure 3.4) are recommended for design of wells to allow the upper portion of the well riser to move independently of the lower portion of the well as the landfill settles. This measure is also intended to address landfill settlement and to reduce the potential for damage to well laterals.

As indicated above, effective drainage of condensate from LFG collection piping is key to the long-term performance of the LFG collection system. The existing condensate drains include a gas seal and allow the liquid to drain back into the landfill. When properly designed, this type of drain will function well if the landfill has the capacity to accept the additional liquid. If the drain is located in an area of the site that is saturated, it may not be possible for the liquid to drain from the pipe into the wastes. In a Site with a high leachate mound such as the Highway 101 Site, it is preferable to drain condensate directly into the leachate collection system. It is understood that the proposed condensate drains to be added have been designed with this intent. It is also noted that the design of the existing condensate drain traps is subject to damage due to landfill settlement. Additional condensate drains may be required to replace non-functional drains on the header piping in the older portion of the Site.

From the monitoring data provided it is apparent that the majority of the vertical extraction wells in the older portion of the Site are not currently operational. Many of these wells are reported as blocked. The monitoring records report blockage of wells 1D, 1G, 1H, 2C, 2F, 2I, 2J, and 2M. This could indicate flooding of the laterals leading to these wells or flooding of the wells themselves. Wells connected to the west portion of the header (from 1B to 1O) are recorded as consistently under positive pressure. This indicates that the main header may be flooded or otherwise blocked at a location north of the lateral to well 1A. The August 1996 data shows a reduced vacuum at well 2E when compared with previous readings and with readings at adjacent wells. This may be an indication of a developing blockage in the lateral leading to well 2E.

Because of the gentle slopes of the header piping and the saturated nature of the landfill, it seems likely that many of these problems may be caused by accumulation of condensate at low spots that may have formed in the piping due to landfill settlement. These problem areas will have to be investigated and steps will have to be implemented to allow collection of LFG from the wells in these areas. Installation of additional monitoring ports on the header will facilitate identification and investigation of problem areas in the piping. If possible, water level measurements should be updated within the wells to determine which can be used for LFG collection. Remedial efforts that may be considered such as installation of additional drains, installation of new laterals/sub-headers, and re-grading of portions of pipe should be focused on wells that are not flooded.

The vertical wells that are in place on the older portion of the landfill are concentrated in the central plateau area. This is a result of limitations on access of the large crane mounted type drill rig that was used to install the large diameter (1000 mm) boreholes for these wells. It would enhance overall LFG recovery if LFG could be collected from a larger portion of the Site area.

There are a number of reservations concerning limitations on the potential effectiveness of vertical LFG collection wells in the older portion of the Highway 101 Site. These concerns arise from the high leachate head at the Site and the layering and segmentation of the wastes resulting from the daily cover material used. These factors would be expected to limit the potential zones of influence of wells installed at the Site thereby requiring a greater number of wells to be installed to achieve the desired recovery. Typical design density for vertical extraction wells is in the range of 1 to 1.5 wells per hectare of landfill area. Due to the daily cover material used and the high leachate head, a well density of 2 wells per hectare would be used as a starting point for design of an effective well field for the older portion of the Site. This would require approximately 125 wells on the older portion of the Site. Examination of the records of leachate elevations for the Site indicates that no more than about 40 of these could be installed and be effective. The criteria for determining this was based on placing wells only in area of the Site where the leachate level is greater than 3 metres below the ground surface. This would be expected to severely limit the recovery effectiveness of a vertical well field. These concerns do not apply to the landfill extension area and it is anticipated that conventional LFG collection system design principles could be successfully applied in that area.

If additional wells are to be installed, significant savings may be achieved by installation of wells in smaller diameter (i.e. 250 mm) boreholes. This may be carried out using standard soil exploration drilling rigs with smaller diameter, continuous flight augers. These compact rigs are highly mobile and can travel on slopes as steep as 3 to 1 without difficulty. It has been CRA's experience at numerous landfills that there is no performance advantage to be gained from drilling large diameter (i.e. 1000 mm) boreholes for LFG extraction wells. The large crane mounted rigs that are required to drill large diameter boreholes are costly, generally have lower productivity than the smaller rigs, and may require construction of on-Site roads to allow access to the drilling locations.

Additional savings may also be achieved by installation of wells only to the depth of the leachate head within the Site. Location of the perforated portion of the well above the saturated wastes optimizes the cost-effectiveness of the LFG collection well.

It is CRA's understanding from staff at the Site that the gas collection piping floods during heavy rainfall events. This indicates a direct connection between the LFG collection piping and the surface of the landfill or the storm water drainage system. This condition interferes with the effective operation of the LFG collection system. From examination of the LFG system construction drawings and inspection of the Site, it is apparent that there are a number of possible locations where storm water could be entering the LFG collection piping. These include the following:

- leachate collection chambers;
- damaged lateral connections at well heads; and
- termination points on the extension area sub-header.

These locations should be investigated to determine the point(s) of entry of the storm water and to allow corrective action to be taken.

Staff at the Site report that operation of the LFG collection trenches located beneath the landfill extension area results in a large influx of air into the system. This response indicates that there is likely an opening to the atmosphere in the LFG collection piping serving the wastes beneath the landfill extension area. Examination of the liner construction drawings for the extension area reveals the following possible locations where air could be entering the system:

- un-sealed sub-header pipe terminations;
- un-sealed horizontal trench terminations at the perimeter berm; and
- insufficient low permeability soil cover over perforated pipes and pipe ends at the landfill extension perimeter berm.

The large air intake from these possible sources interferes with the ability of the system to collect LFG from beneath the extension area. As a result of this air leakage, the horizontal LFG collection trenches have not been in operation since installation in 1994. The possible sources of air leakage into the piping should be investigated and addressed. Some of these sources of air leakage may also be related to the entry of storm water into the LFG piping.

The primary constraints on recovery of LFG from the older portion of the site are due to the elevated leachate head and the stratification of the wastes. These limitations are not present in the smaller landfill extension area. It is anticipated that reasonable rates of LFG recovery can be achieved from the landfill extension area wastes with a suitably designed collection field.

3.2.1 Landfill Gas Collection System Optimization

Significant improvements to LFG collection must be made if LFG utilization is to be considered. Optimization of LFG recovery will provide better control of LFG related impacts. The following discusses methods to improve LFG recovery at the Highway 101 Site.

Collection of a larger portion of the LFG that is produced may require upgrades to the LFG control plant. Currently the plant has the capacity to collect up to 11.3 m^3/min. (400 cfm)of LFG and flare up to 30.5 m^3/min. (1077 cfm). It is expected that optimization of LFG recovery would require additional collection capacity in the form of blower(s) and may also require additional flaring capacity. These modifications would best be accomplished by expansion of the existing LFG collection plant.

Expansion of the collection field would be required to collect a larger proportion of the LFG that is produced. The conditions in the older portion of the landfill require specific design modifications to improve the effectiveness of the collection field. Three options for collection field design concepts which would improve LFG recovery on the older portion of the landfill include:

- Option 1: Repair and expand existing vertical collection well field;
- Option 2: Repair existing well field and expand collection field using horizontal collection trenches; and
- Option 3: Construct a LFG collection layer with geosynthetic membrane.

The following discusses considerations/constraints and the relative advantages and disadvantages associated with each of these options. It should be noted that the cost estimates associated with each of the options presented in Table 3.1 are approximations based on the design concepts discussed. The estimated costs are presented for comparison purposes and to aid in decision making.

<u>Option 1</u>

This approach makes use of additional vertical LFG collection wells and would include the following:

- investigate and repair existing problem areas identified in Section 3.2;
- modify well design to accommodate high leachate levels;
- install additional wells only in areas where the leachate level is more than 3 metres below ground surface; and
- install additional collection piping and drains.

It should be recognized that in the older portion of the Site, because of the high leachate head and the low permeability daily cover soil, the zones of influence of vertical wells will be limited. As a result of this, to achieve reasonable collection effectiveness and avoid drawing of excessive amounts of air into the Site, vertical wells would have to be placed close together. As discussed in the previous Section, a starting point for design would be to allow for a minimum of 2 wells per hectare. This translates to a minimum initial well spacing of 70 to 80 m. which would require a total of 125 wells for the older portion of the Site. However, due to the high liquid level within the Site, the maximum number of effective LFG extraction wells that can be installed is approximately 40.

There are concerns regarding the potential detrimental effects of settlement and possible flooding of collection pipes under Option 1. These issues can be addressed somewhat by design features (i.e. pipe grading, drainage) and on-going maintenance of the system. This contributes to the cost of this option.

The efficiency of the Option 1 collection field would be expected to be significantly better than what is currently being achieved but less than the other options. It is expected that the Option 1 collection field would be able to collect 20 to 25 percent of the LFG that is produced from the older portion of the Site.

As the same limiting conditions do not exist in the landfill extension area, a vertical well field in this area would be expected to be capable of collecting 50 to 60 percent of the LFG produced.

The Option 1 approach makes use of as much of the existing LFG collection field as possible. The cost of this option, as shown on Table 3.1 is the lowest of the approaches under consideration. It should be noted that the costs associated with investigation and repair of the problem areas in the existing LFG collection field cannot be defined at this time. An allowance amount to represent this has been included in Table 3.1.

Option 2

This approach makes use of horizontal LFG collection trenches and would include the following:

- investigate and repair existing problem areas identified in Section 3.2;
- install a grid of horizontal collection trenches on areas of the older portion of the Site which do not currently have collection wells;
- trenches to be excavated into the wastes just beneath the existing cover in areas where the leachate level is more than 1 metres below ground surface; and
- install additional collection piping and drains.

As with Option 1, a fairly high density of horizontal collectors would be required to achieve reasonable collection efficiency. A horizontal spacing of approximately 25 m. has been assumed. This option sacrifices some of the fine areal control that adjustment of individual wells provides. However this is off-set to some degree by a more uniform distribution of LFG collection coverage.

There is less concern for Option 2 compared with Option 1 regarding the detrimental effects of settlement and flooding of pipes. The horizontal collectors would be perforated pipes bedded in coarse sand or gravel and as such would be expected to drain any liquid into the wastes. The grid pattern of horizontal collection piping which is proposed, provides numerous alternate routes for LFG flow should localized flooded spots develop. This advantage is reflected in lower operation and maintenance costs

The efficiency of the Option 2 collection field would be expected to be significantly better than what is currently being achieved, and also somewhat better than for Option 1. It is expected that the Option 2 collection field would be able to collect 30 to 40 percent of the LFG that is produced.

The Option 2 approach on its own is not considered applicable for the landfill extension area. However, Option 3 incorporates the horizontal collector grid concept into an approach that can be applied on the landfill extension area.

Option 2 makes use of as much of the existing LFG collection field as possible. It should be noted that the costs associated with investigation and repair of the problem areas in the existing LFG collection field cannot be defined at this time. An allowance amount to represent this has been included in Table 3.1.

Option 3

This approach makes use of a continuous LFG collection layer and would include the following:

- construction of a LFG collection layer on the existing landfill surface incorporating the following design elements:
  - a continuous coarse sand or gravel LFG collection blanket;
  - a grid of horizontal collector pipes placed within the LFG collection layer;
  - a geosynthetic membrane on top of the LFG collection layer;
  - soil ballast on top of the membrane; and
  - vegetation cover

Option 3 requires some co-ordination to allow construction of the LFG collection layer. This will include some surface re-grading, and design considerations to modify existing chambers, monitoring wells/risers, etc. to allow incorporation into the LFG collection layer. It is critical that the design of the LFG collection layer properly interface with other Site engineering features such as stormwater management, leachate control, and closure plans.

The synthetic membrane minimizes the potential for leakage of air into the Site. This factor, combined with the continuous coverage of the LFG collection blanket means that the collectors can be spaced much further apart (i.e., 60 m.) than for Options 1 and 2. Concerns regarding the detrimental effects of settlement and flooding of piping on LFG collection are minimized with Option 3. This is reflected in the lower operation and maintenance costs for this option.

Option 3 provides the highest level of LFG collection efficiency that can reasonably be achieved. It is expected that 80 percent or more of the LFG that is produced can be collected using this approach. This high level of LFG collection efficiency will provide the highest degree of control of LFG odours and atmospheric emissions.

The Option 3 approach will also reduce or eliminate infiltration of moisture into the landfill. This may have beneficial effects on leachate seepage control and groundwater conditions. The LFG collection layer may also be designed to reduce contact of precipitation with leachate, possibly reducing the quantity of liquid which must be treated on-Site. The Option 3 approach is also applicable for the landfill extension area.

This approach does not make use of the existing LFG collection field. The cost of this option, as shown on Table 3.1 has the highest cost of the three options under consideration.

Option 4

Option 4 is a combination of Options 2 and 3. This combined approach is presented to allow evaluation of a less costly approach than Option 3 and to be consistent with current plans for capping of the landfill extension area. Option 4 makes use of LFG collection trenches for the older portion of the landfill as described under Option 2 and a geomembrane cover system applied to the landfill extension area as described under Option 3.

Option 4 represents the highest rate of LFG recovery that can be achieved within a reasonable cost range and in a manner that is consistent with the current design philosophy for the Site.

Summary of Collection Field Options

Option 1, which includes upgrading and expansion of the existing vertical collection well field, is the lowest cost option available and would be expected to provide the lowest overall rate of LFG recovery of the options available.

Option 2 includes upgrading the existing well field, construction of trenches on the older portion of the site, and installation of a conventional well field in the life extension area. Option 2 is a low cost approach which offers slightly better LFG recovery than Option 1.

Option 3, which includes construction of a continuous LFG collection layer over the entire Site, is the highest cost option available and has the highest potential LFG recovery.

Option 4, which makes use of horizontal collection trenches on the older portion of the Site and a continuous LFG collection layer on the life extension area, is a moderate cost approach which offers a reasonably good rate of LFG recovery. Option 4 is consistent with the planned program for capping of the life extension area and therefore represents a potentially cost effective method of combining the capping and LFG collection programs. Option 4 is recommended for further consideration towards integration with the Site capping program.

4.0 LANDFILL GAS UTILIZATION

The collection and use of LFG as an energy resource offers important environmental and economic benefits. Utilizing LFG requires an effective LFG collection system and process equipment to generate energy or produce end products. The utilization system as a whole offers significant environmental benefits to control such impacts as air quality (reducing odorous emissions), off-Site gas migration (potential explosion hazards) and greenhouse gas emissions. The economic return from utilizing the recovered LFG can off-set a portion of the landfill's operation and maintenance costs.

The USEPA considers that LFG utilization provides a unique form of recycling[1]. The gas generated in landfills is returned to the public in the form of usable energy or end product. Making use of the LFG generated in landfills as an energy resource conserves other resources such as fossil fuels.

The opportunities for LFG utilization are related to the end-products which may be produced and the markets that are available for those end products. The feasibility of LFG utilization is largely controlled by the nature of the LFG resource, the cost of production of energy or end products, and the market price that is available. A LFG utilization project must be economically viable to be undertaken.

4.1 LFG UTILIZATION OVERVIEW

The following presents a brief overview of the current technologies for LFG utilization.

LFG contains primarily methane and carbon dioxide with trace quantities of sulphur compounds, volatile organic compounds (VOC's), and moisture. The resource value of LFG is derived largely from the methane

[1] Nichols, Mary, USEPA, "Landfill Gas Energy Recovery: Turning a Liability into an Asset", August 1997 Waste Age Magazine.

component and in some instances also from the carbon dioxide fraction of LFG. The trace compounds and moisture are responsible for the potentially corrosive nature of LFG which is detrimental to the equipment used in many LFG utilization technologies.

Different levels of processing of LFG are required to create the end-products for sale in the various markets. The different categories of LFG processing results in the following outputs:

- minimal treatment ⇒ low grade LFG fuel;
- trace compound removal and drying ⇒ medium grade LFG fuel; and
- trace compound removal, drying, carbon dioxide separation ⇒ high grade LFG fuel and by-products.

Within each level of processing, a number of technologies are available to create LFG derived energy and products for end users. The following briefly describes the possible applications for outputs from each of the levels of processing.

4.1.1 Low Grade LFG Fuel

LFG can be used for various heating applications with minimal pre-treatment of the gas. These application include space heating, fueling a furnace or drying kiln, and process heating, among others. Due to the relatively low heating value of the raw LFG the process equipment must be designed to operate on this fuel. Typically the LFG is transported to the user through a dedicated supply pipeline and therefore proximity of the end-user to the landfill is an important consideration. Many heating applications such as space heating are cyclical with hourly, daily, and seasonal variations in energy demand loads.

Raw LFG may be utilized as fuel for boilers to produce steam for heating or generation of electricity. The gas requires minimal treatment and compression for use in the gas fired burner of a power boiler producing high pressure steam. The steam from the boiler may then be used for process or space heating applications. A suitable user should be located in close proximity (i.e. < 10 km.) to the Site to make this alternative feasible. Steam from the boiler may also be used to produce electricity with a steam turbine. The high maintenance required for the operation of a steam turbine electrical generation plant makes it generally necessary for the plant size to be in the range of 10 to 50 mega Watts (MW) to ensure economic feasibility.

Proprietary systems are available which use LFG to evaporate leachate leaving only a small quantity of sludge or dry ash for disposal. Air emissions regulations, requirements for disposal of the sludge or ash, and the cost of alternative forms of leachate management are factors that need to be evaluated when considering this LFG utilization approach.

4.1.2 Medium Grade LFG Fuel

Upgrading the raw LFG to medium grade fuel increases costs due to the treatment required. Treatment of the gas involves some reduction of trace contaminants and moisture content. The energy content of the gas is not affected by this level of treatment. Medium grade LFG fuel may be used as a heating fuel or to generate electricity.

Utilizing medium grade LFG as heating fuel for industrial boilers, dryers, kilns or gas furnaces can be viable if the end user consumes large volumes of energy on a year around basis and is located in close proximity to the site. The additional costs of upgrading the gas may be justified by the requirements of the equipment that is used to handle the gas. The corrosive nature of untreated gas may result in increased maintenance costs and/or equipment failure. An alternative source of fuel should be readily available to supplement the LFG for critical heating applications.

Well established technologies are available for the production of electricity from medium grade LFG. Generation of electricity from LFG has the advantage of avoiding limitations imposed by the end-users' demand variations and proximity to the landfill.

Medium grade LFG may be used as a fuel for reciprocating engines and gas turbines which in turn drive generators to produce electricity. Gas turbines offer flexibility to proceed directly to the combined cycle option for electrical generation in the future, should LFG production or power pricing warrant. A combined cycle plant uses gas turbine(s) and boilers with steam turbine(s) to produce electricity. The main differences between reciprocating engines versus gas turbines are the available unit sizes, the efficiency of units, the required LFG supply pressure, and maintenance costs. The two units have similar requirements with respect to LFG treatment, electrical hook-up and building and civil works.

Reciprocating engines are available in various sizes with electrical outputs ranging from 0.5 MW to 12 MW per unit. Reciprocating engines have a comparatively low capital cost per kW, high efficiency and relatively high maintenance cost, since it requires near full time attention from trained personnel. Gas turbines are generally larger than reciprocating engines with electrical outputs ranging from 3 MW to 18 MW for each unit. Gas turbines usually have a higher capital cost associated with initial set up and offer slightly lower energy conversion efficiencies compared to reciprocating engines. Gas turbines offer superior emissions, reduced operating and maintenance costs and greater operational flexibility than reciprocating engines.

Combined cycle plants have high efficiency, good emissions, high capital costs, and are generally cost effective only for operations with greater than 10 MW output.

The reciprocating gas engines are the most common and successful of the small to medium sized LFG utilization options to produce electricity that have been selected by developers. A key reason for the popularity of this technology is the flexibility that reciprocating engines provide in sizing of utilization plants.

4.1.3 High Grade LFG Fuel and Other Products

High grade fuel requires further treatment of the LFG that involves the removal of carbon dioxide, moisture, and trace contaminants, such as VOCs, sulfur compounds and hydrogen sulfide. The end product is a fuel with high energy content similar in nature to pipeline quality natural gas. Possible end uses of the products of refined LFG include sale to natural gas utilities or natural gas consumers, commercial sale of carbon dioxide, production of chemical products, electrical generation and vehicle fuel. Treatment of LFG to produce high grade fuel is costly and success with these types of projects has been limited.

Fuel cells are an emerging technology for LFG utilization. Fuel cells convert hydrogen directly into electricity. In LFG applications, the hydrogen is produced by processing LFG. Fuel cell systems have a high level of energy conversion efficiency and good emissions. Utilizing fuel cells for electricity generation from LFG has been carried out in pilot scale projects. This utilization option is not currently competitive on an economic basis with other options to produce electricity from LFG. Additional research and development into gas treatment and fuel cell technology is expected to improve the economics of this option in the future. Due to the high costs, no further evaluation of electrical generation from LFG using fuels cells will be undertaken in this report.

As noted, treatment of LFG to produce high quality gas requires separation of the carbon dioxide fraction which itself has some commercial value. Commercial sale of carbon dioxide from LFG is generally undertaken as a sub-component of a program to produce high grade fuel from LFG.

Proprietary systems are available to produce methanol from LFG. Methanol has uses as a chemical feedstock and as a fuel additive. CRA is not aware of any projects where this has been undertaken as a successful long-term application for LFG utilization. No further evaluation of this option will be undertaken in this report.

LFG may be converted into vehicle fuel. This involves separation of most of the carbon dioxide along with removal of moisture and many of the trace compounds. The treated fuel is compressed for use in vehicles which require modifications to run on LFG. The use of LFG as a vehicle fuel holds promise as an emerging LFG utilization technology to reduce gasoline/diesel fuel consumption while improving vehicle emissions. Due to high treatment costs and the cost of conversion of engines to use compressed LFG, the economics of this technology are currently not competitive with other utilization options. This type of utilization project has been undertaken at a number of sites as pilot scale programs and holds significant promise due to the environmental benefits that are offered. It is expected that future research and development into LFG treatment and engine technology will reduce the costs of this option. No further evaluation of this option will be undertaken in this report.

4.2 MARKET REVIEW

The following discusses potential opportunities that are available for utilization of LFG from the Highway 101 Landfill Site. These opportunities are categorized as being either on-Site or off -Site.

On-Site LFG Utilization

The following potential opportunities for on-site utilization of LFG have been identified:

- heating fuel for the existing leachate treatment facility;
- electrical power generation for on-Site use; and,
- leachate evaporation.

It is understood that the boilers in the leachate treatment facility are configured to operate on either No. 2 heating oil or raw LFG. The boilers provide heat for the anaerobic reactors and for heating of the building. During 1996 approximately 100,000 litres of oil was used in the boilers.

Approval has not yet been given to run the boilers on LFG, which consume energy at the rate of approximately 354,000 BTU/hr. averaged over the course of a year. This represents an averaged rate of LFG consumption of approximately 24 m^3/hr. (14 cfm). Some augmentation of the LFG with other fuels may be required to attain the heating value required to run the boilers. Based on local market pricing for No. 2 heating oil, use of LFG to run the boiler would result in a savings of approximately $30,000 to $40,000 per year depending upon the extent of fuel augmentation that is required. It is recommended that the necessary Approvals continue to be pursued as this represents a significant annual savings and a positive use of the existing LFG resource. As the process equipment for this option is already in place, it will be assumed that 25 m^3/hr (15 cfm) of LFG will be used at the leachate treatment facility in all further evaluations.

It has been reported that during the period from June 1995 to August 1996 inclusive, approximately 2,174 megaWatt•hours (MW•hrs.) of electrical power was consumed at the leachate treatment plant. This represents an averaged power load of roughly 150 kiloWatts (kW). The cost of this electricity consumption is approximately $115,000 per year. This represents an opportunity to use LFG to generate electrical power for on-Site usage. This opportunity will be considered further in the technical and economic evaluation in conjunction with other electrical generation concepts.

Use of LFG to evaporate leachate could expand the overall quantity of leachate that could be treated at the Site. Manufacturers information indicates that with the minimum plant size for leachate evaporation, 46 Litres per minute (10 gallons per minute.) of leachate could be treated using 1020 m^3/hr. (600 cfm) of LFG. An economic evaluation of this LFG utilization opportunity would require comparison with other alternatives for adding leachate treatment capacity. This utilization option will not be evaluated further in this report as the necessity of expansion of leachate treatment has not been identified as a priority for the Site.

Off-Site LFG Utilization

The following potential opportunities for off-site utilization of LFG have been identified:

- direct use of LFG as a low grade heating fuel;
- production of high grade fuel for sale to utilities/end-users; and
- sale or "wheeling" of electrical power from LFG for off-site uses.

To assess the potential for off-Site direct use of LFG as a low grade heating fuel, an inventory of the nearby energy users was carried out. Land use in the immediate vicinity of the Site (<2 kilometres) is generally rural, small scale industry, or undeveloped and contains no large scale energy consumers. Several large energy consumers were identified within a distance of approximately 2 to 10 km of the Site. Figure 4.1 shows the locations of these energy consumers and presents information on their energy usage. As Nova Scotia does not currently have a natural gas distribution infrastructure, most of the energy consumption identified is currently supplied by electricity. Some consumers in the area have seasonal use of oil or propane for heating. Due to the high costs of delivery of the gas, the lack of existing gas burning heating equipment, and the cyclical nature of the demand identified, no further evaluation of LFG as a low grade heating fuel for off-Site use will be undertaken in this report.

Similarly, the lack of an existing natural gas distribution infrastructure dictates that there is no ready market for sale of high grade fuel produced from LFG. No further consideration of upgrading LFG to pipeline quality gas will be undertaken in this report.

Electrical generation using LFG as a fuel is a proven technology that has been successfully implemented at numerous landfill sites in the past. Several alternatives are available for electricity production at the Site. The electrical power generated may be used on-Site, "wheeled" through the transmission grid, and/or sold to the local utility.

The provincial electrical power utility, Nova Scotia Power Inc. (NSP), was contacted by CRA to discuss production of electrical power from LFG. The following points were covered in the discussion:

- NSP is interested in the concept of utilization of LFG particularly as a method of reducing greenhouse gas emissions;
- NSP considers proposals for non-utility power generation on a case-by-case basis;
- NSP is capable of purchasing electricity produced from LFG at the Highway 101 Site, however, currently NSP has surplus generating capacity. As a result, payment for electricity would be at the avoided cost rate of approximately \$0.03/kW•hr;
- "Wheeling" power involves contribution of electricity into the transmission grid at one facility to off-set consumption of power at another facility. The generating and consuming facilities must be owned by the same corporation. The quantity of electricity contributed to the grid must be less than the quantity consumed. A "wheeling" fee of approximately \$0.01/kW•hr would be charged; and
- NSP would be willing to discuss various types of business arrangements for a LFG to energy project including joint ventures.

The Halifax Regional Water Commissions' Water Supply Plant at Pockwock Road consumes an average of 900,000 kW•hr of electrical power per month. The Pockwock Road plant may be one good candidate for the consumption side of a "wheeling" arrangement. Dependent upon the amount of electricity produced, other candidate facility may also need to be considered. Any arrangement to produce electrical power for sale to the utility or "wheeling" into the grid would be subject to negotiation of a suitable agreement between the power producer and NSP.

4.3 EVALUATION OF UTILIZATION OPTIONS

Based on the preceding market review, opportunities for LFG utilization at the Highway 101 Site include the on-Site use of LFG to fuel the boilers in the leachate treatment plant, and generation of electricity for use on-Site and off-Site.

It has been recommended that the Approvals required to allow on-Site use of LFG to fuel the boilers in the leachate treatment plant continue to be pursued as this offers significant savings, requires little or no additional capital expenditure, and provides a positive use of the existing LFG resource. Staff of the Halifax Regional Municipality are actively pursuing this course of action. Based on the information provided it is CRA's understanding that the quantity of fuel required by the boilers could be provided by the LFG collection system as it is currently operating. This is the only LFG utilization option available at the Highway 101 Site which does not require extensive modification to the collection field. There is no further technical or economic evaluation of this option required. For the evaluation of other options it will be assumed that 25 m^3/hr (15 cfm) of LFG will be used at the leachate treatment facility.

The following sections will provide the technical and economic evaluations of electrical generation from LFG.

4.3.1 Technical Evaluation

The objectives of the technical evaluation are to assess the Site specific considerations of each of the LFG utilization technologies being contemplated, and to determine the preferred approach(es) to LFG utilization.

Factors to be considered in the evaluation of LFG utilization technologies include the following:

- compatibility with LFG recovery (plant sizing);
- "track record"/reliability;
- technical feasibility;
- energy conversion efficiency;
- environmental considerations (emissions, noise, wastes, etc.); and
- provision for future expansion needs.

Generation of electrical power from LFG at the Highway 101 Site requires improvement of LFG recovery as identified in Section 3.3. The Site is reaching its peak phase of LFG production and therefore the quantity of LFG that may be collected depends on the timing of implementation of the LFG collection field optimization.

The options available for electrical generation include reciprocating engines, gas turbines, LFG boiler with steam turbines, and combined cycle plants. The following are guidelines for selection of technologies for generation of electricity from LFG:

Technology	*Typical Site Size (M Tonnes)*	*Preferred Plant Size (MW)*	*Minimum Methane Content (%v/v)*	*Gross Plant Efficiency (%)*
Reciprocating Engines	1 - 8	0.5 - 12	45	~35
Gas Turbine	3 - 12	3 - 8	40	~27
Boiler with Steam Turbine	>6	10 - 50	20	~33
Combined Cycle	>10	>10	40	~37

Based on the site size criteria shown, use of either a boiler/steam turbine, or a combined cycle plant would not be expected to be feasible. Using a rule of thumb of approximately 800 to 1200 kW per million tonnes of municipal solid waste with a 50 to 70 percent allowance for the expected LFG recovery rate, it can be estimated that LFG from the Highway 101 Site can generate in the range of approximately 1.6 to 3.4 MW of electrical power. This indicates that the preferred plant size would fit best in the category defined for reciprocating engines.

Selection of the preferred technology will be based on a comparison of gas turbines and reciprocating engines. The following lists advantages and disadvantages of each of these two technologies in the context of LFG utilization at the Highway 101 Site:

Reciprocating Engines		*Gas Turbines*	
Advantages	*Disadvantages*	*Advantages*	*Disadvantages*
• Small to medium sized projects	• Pre-treatment of fuel required		• Medium sized projects
• Small modular units give plant sizing flexibility	• Disposal of waste oil is required	• Modular units give plant sizing flexibility	• Larger modular units
• Lower capital cost	• High operation & maintenance costs	• Lower operation & maintenance costs	• Higher capital costs
• Good energy conversion efficiency	• Sensitive to minimum CH_4 concentration (45%)	• Less sensitive to CH_4 variations	• Lower energy conversion efficiency
	• Control of emissions required	• Good emissions	
• Proven track record with LFG	• Noise abatement required	• Proven track record with LFG	

One of the primary considerations in selection of a utilization technology is compatibility of the expected LFG recovery with the incremental size of the plant that can be provided. This allows optimization of the use of the LFG and the cost of the plant. Based on the plant sizes available, reciprocating engines offer a better "fit" with the expected rates of LFG recovery than gas turbines. There is no gas turbine currently available which matches well with the rate of LFG recovery expected at the Highway 101 Site. The primary rationale for discontinuation of evaluation of gas turbines is incompatible plant sizing.

Reciprocating engines have the disadvantages of higher operation and maintenance costs, requirements for disposal of waste oil, and noise and emission controls. These disadvantages can be addressed through the design of the facility and the operation and maintenance program that is implemented. This however adds to the cost of a reciprocating engine project. These additional costs are included in the economic assessment of the different options.

The primary disadvantage with reciprocating engines is the sensitivity to fluctuations in the methane content of LFG. This is not normally a concern at Sites with low permeability covers. At the Highway 101 Site the potential for drawing air into the system is greater than typical due to the high liquid level at the Site. This is a matter to be addressed in the design of the collection field and with careful operation of the system. At some Sites, LFG is augmented with natural gas to maintain energy. Natural gas is not available at the Highway 101 Site.

In the event that the LFG methane content declines below approximately 45% (~400 BTU/cubic foot) reciprocating engines can be "de-rated" or throttled to operate at lower gas flows. This would be carried out in conjunction with adjusting the collection field to reduce the draw on the Site thereby reducing the air leakage into the Site.

Reciprocating engines can also be designed or modified to operate on fuels which have energy content lower than 400 BTU/cubic foot to accommodate lower methane content LFG. This measure has not been assumed to be required in the economic evaluation.

Reciprocating engines have significantly higher efficiency and lower capital costs than gas turbines. This means that a higher energy output can be achieved for a lower initial capital investment when using reciprocating engines. The costs to operate and maintain a reciprocating engine plant are higher than for gas turbines.

Based on the preceding, electrical generation from LFG using reciprocating engines has been determined to be a technically suitable approach to LFG utilization. This will be used as the basis for the economic evaluation of LFG utilization for the Highway 101 Site.

4.3.2 Economic Evaluation

Cost/revenue projections were prepared for various scenarios of electrical generation from LFG using reciprocating engines. Other options considered were found to have no established markets for outputs, or were not technically suited to the Highway 101 Site and therefore were not included in the economic evaluation.

For the option of wheeling power to another HRM facility, the resulting savings are considered as revenue in this evaluation. The savings are the difference between the rate being paid to NSP for electricity less the wheeling fee. Power rates charged by NSP vary in the range of approximately \$0.055 to \$0.085 per kW•hr for industrial consumers. The exact rate is dependent upon the demand load of the consumer. For the purpose of this evaluation a rate of \$0.065 per kW•hr has been assumed to represent a typical rate for a medium sized industrial consumer.

The financial projections are provided as a preliminary indication of the economic feasibility of LFG utilization at the Site, and to allow an equitable basis for comparison of the options. Should a LFG utilization project proceed, a detailed financial analysis should be conducted.

The following criteria and assumptions were adopted to conduct an economic evaluation:

- scenarios are evaluated over 20 years, beginning in 1998, since the replacement cycle of the utilization equipment is in the range of 20 to 30 years. Also it is difficult to predict economic conditions beyond 20 years. All cost/revenue projections were estimated in 1997 dollars;
- 15 cfm of LFG is deducted from the LFG recovery projections to operate the boilers in the leachate treatment plant. This represents an "automatic" savings of \$40,000 per year;
- LFG composition is approximately 50 percent methane by volume with 450 Btu/scf heating value;
- the plant availability (total operating hours/total available hours) was assumed to be 98 percent for multiple engine scenarios and 95 percent for the single engine scenario ;
- the engine's conversion efficiency was estimated to be 36 percent at full capacity;
- capital costs are financed at 6 percent for the period of time necessary to ensure positive cash flow;
- the rate received from NSP for power purchased is assumed to be
- \$0.03/kW•hr;

- the rate paid to NSP for power consumed is assumed to be $0.065/kW•hr;
- the "wheeling" fee required by NSP is assumed to be $0.01/kW•hr;
- initial operating and maintenance costs were set at $0.018/kW•hr which is typical for this type of technology and were escalated at 2 percent per annum.

All options considered suitable for utilization were based on generation of electrical power via reciprocating engines. This type of utilization requires a LFG collection field, a control plant, reciprocating engine/generator sets, primary gas treatment equipment, mechanical and electrical controls, and electrical connections.

The cost of installing an electrical generation station was estimated based on costing yardsticks and previous utilization projects. The plant size was selected to suit each of the scenarios. The costs of modifying and subsequently operating the LFG collection field were excluded from this economic evaluation as these costs are more related to controlling potential LFG impacts than to LFG utilization. The following four utilization scenarios were defined for the economic evaluation.

<u>Scenario 1</u>

In Scenario 1 it is assumed that electrical power is produced to meet the needs of the leachate treatment plant (150kW) and excess power is "wheeled" to off-Site facilities such as the Pockwock Water Supply Plant and others. The savings projected from this Scenario are calculated based on $0.065/kW•hr for the portion of power used on-Site, and $0.055/kW•hr (savings less fee) for that portion of power that is wheeled off-Site. The LFG recovery assumed for this scenario is based on recovery of 70 percent of the average of the range of LFG production expected from the entire Site. To achieve this rate of recovery would require the use of Option 3 for the collection field as described in Section 3.3. The economic evaluation of Scenario 1 is presented on Table 4.1.

Scenario 1A

In Scenario 1A the rate of LFG recovery was assumed to be 30 percent for the older portion of the landfill and 80 percent for the landfill extension area as outlined in Option 4 of the collection field design approaches. As above, these recovery percentages are calculated based on the average of the range of LFG production expected. These rates of recovery are consistent with what would reasonably be expected using Option 4 as descibed in Section 3.3. The output of the plant, and hence the capital cost of the plant, have been adjusted accordingly to reflect the expected rates of LFG recovery. All other conditions used in Scenario 1A are identical to Scenario 1. The economic evaluation of Scenario 1A is presented on Table 4.2.

Scenario 2

In Scenario 2 it is assumed that electrical power is produced to meet the needs of the leachate treatment plant and excess power is sold to NSP. The savings projected from this Scenario are calculated based on $0.065/kW•hr for the portion of power used on-Site. Revenue is projected based on the power purchase rate of $0.03/kW•hr. The LFG recovery assumed for this scenario is based on recovery of 70 percent of the average of the range of LFG production expected from the entire Site. To achieve this rate of recovery would require the use of Option 3 for the collection field as described in Section 3.3. The economic evaluation of Scenario 2 is presented on Table 4.3.

Scenario 2A

In Scenario 2A the rate of LFG recovery was assumed to be 30 percent for the older portion of the landfill and 80 percent for the landfill extension area as outlined in Option 4 of the collection field design approaches. As above, these recovery percentages are calculated based on the average of the range of LFG production expected. These rates of recovery are consistent with what would reasonably be expected using Option 4 as described in Section 3.3. The output of the plant, and hence the capital cost of the plant, have been adjusted accordingly to reflect the lower rates of LFG recovery. All other conditions used in Scenario 2A are identical to Scenario 2. The economic evaluation of Scenario 2A is presented on Table 4.4.

Summary of Economic Evaluation

Scenarios 1 and 1A are deemed to be economically feasible given the previously stated conditions regarding recovery of LFG. Comparison of the results shown in Tables 4.1 to 4.4 clearly demonstrates the financial significance of the savings resulting from on-Site use and "wheeling" of electrical power generated from LFG.

In Scenario 1, positive cash flow is maintained from savings on the purchase of electricity, and the project financing is covered after four years of operation. The net present value (NPV) in 1997 of Scenario 1 is the highest of the options considered at $14.3 million. This is more than double the next highest option. Calculation of NPV compares the overall cost and revenue streams of an investment adjusted to a given date. In general terms, an investment with a positive NPV is considered acceptable but the option with the highest NPV is the best investment alternative. The LFG utilization option presented in Scenario 1 is considered economically feasible.

In Scenario 1A, positive cash flow is maintained from savings on the purchase of electricity, and the project financing is covered after ten years of operation. The net present value (NPV) in 1997 of Scenario 1A is $5.9 million. Scenario 1A is also considered an economically feasible approach to LFG utilization.

For both Scenario's 2 and 2A, positive cash flow cannot be achieved within the expected 20 project life and NPVs are negative. Scenario's 2 and 2A are not considered economically feasible. This is due to the low purchase rate for electrical power.

While Scenario 1 offers a significantly higher return on investment, it should be recognized that this requires the $7.8 million capital investment for capping the entire Site as described under Option 3 in Section 3.3.

This large capital expenditure has not been factored into the economic evaluation.

Scenario 1A provides a reasonable return on the initial investment while requiring only a moderate capital investment for improving LFG recovery as described in Section 3.3 under Option 4. The assumptions regarding the LFG recovery approach are compatible with the current plans for Site closure. It is recommended that the LFG utilization approach described under Scenario 1A be given further consideration and also that integration of Option 4 for improvements to the LFG collection field be reviewed in the context of the current plans for Site closure.

It should be noted that the economic evaluation is generally conservative. Other factors which could be incorporated into the implementation of LFG utilization to further optimize the economics of the project include the following:

- advantageous selection of candidate wheeling site(s) based on consumption and rates;
- consideration of the value of greenhouse gas reductions;
- alternative funding arrangements to reduce financing costs; and
- consideration of joint venture development options including partnerships involving utilities, utilization developer, and/or major equipment suppliers.

4.4 IMPLEMENTATION PROGRAM

Based on the assessments of LFG production, recovery, available markets, and utilization technologies it has been concluded that production of electrical power using reciprocating engines is a possible option for LFG utilization for the Highway 101 Landfill Site. The economic evaluation demonstrates that generating and "wheeling" electrical power is economically feasible and is the most attractive option, subject to the requirements to improve LFG recovery and the assumptions incorporated into the evaluation. The following presents a program to implement LFG utilization at the Highway 101 Site based on the approach described in Scenarios 1 or 1A.

The following is a general overview of the steps required for implementation of a LFG utilization development at the Highway 101 Site:

1. Review collection field improvement options and select approach.
2. Conduct a detailed baseline financial analysis.
3. Decision to proceed with LFG utilization and decision on structure of business arrangement.
4. Implement modifications to the LFG collection field.
5. Establish business arrangement.
6. Negotiate various agreements required.
7. Establish financing.
8. Obtain permits/approvals.
9. Construction phase.
10. System start-up.

It should be noted that these steps can require some time to carry out. As the Site is currently near its peak LFG production rate it is important that, if LFG utilization is to proceed, an implementation program be initiated as soon as possible. LFG should be considered as a perishable resource that is environmentally beneficial. Once LFG escapes from the Site, it enters the environment where impacts may result and it is no longer available for utilization.

As indicated previously, utilization of LFG at the Highway 101 Site requires modification to the LFG collection system to improve the recovery of LFG. This enhanced LFG recovery will provide a higher degree of mitigation of potential LFG impacts. It is recommended that a program to improve LFG recovery that is compatible with the plans for engineering of the Site and LFG utilization, be carried out as soon as possible .

A decision to proceed with LFG utilization must be made prior to carrying out the subsequent steps identified in the implementation program. A detailed financial analysis of the project forms a component of the decision making process. Once a decision to embark on a LFG utilization venture has been reached and the implementation program has begun, re-assessment of the financial analysis should be carried out at major decision points in the implementation program. This is to ensure that the financial projections for the project remain up-to-date with changes as the project is developed.

The decision to develop LFG utilization should consider the preferred business arrangement for implementation of the project. Possible business arrangements include the following:

- public development;
- private development; and
- joint venture.

Within each of these options there are several possible arrangements that can be considered. In a public development ownership is retained by the public body responsible for the Site. Services to develop, construct, operate and maintain the facility can be contracted. Payment for these services can be on a fee or percentage basis. This approach provides the greatest return to the public body and carries with it the highest potential risk and the highest degree of direct involvement required. This approach generally requires a high level of in-house expertise and commitment of resources to the project.

Alternatively, the project can be awarded to a private firm to develop, construct, maintain, and operate the facility. Private development arrangements generally involve sale of the rights to the LFG to the developer in return for payment of a royalty. This approach provides the lowest financial return to the Site owner while minimizing risk and direct involvement in the project.

Both of the above approaches have been applied successfully on LFG utilization projects. A third alternative is to enter into a joint venture with other public and/or private corporations to develop the LFG utilization project. This approach is essentially a combination of the approaches described above. The joint venture has the advantage of allowing the various parties involved to tailor their desired return/risk through agreement with the other members of the joint venture for distribution of responsibilities and payments

The choice of which business arrangement to apply to LFG utilization is a matter of the preferences and policies of the parties involved in the project and is beyond the scope of this report. The business arrangement selected dictates the financial profile of the project and the ownership arrangements may effect the option of "wheeling" of power.

The method of establishing the desired business relationships is dependent upon the approach taken. One common approach is to advertise a Request for Proposals (RFP) from qualified organizations. Due to the numerous methods of LFG utilization that are available, it is recommended that RFP's be based on a well defined scope of the project. This will allow a basis for comparison and evaluation of proposals. Proposals should be evaluated based on the following criteria: feasibility, financial return, environmental considerations, technology, guarantees, and experience of the proponent.

Agreements must be negotiated with the parties involved in the project. These agreements provide a legal definition of the roles and responsibilities of the various parties involved. Negotiation of these agreements may include establishment of project financing. In the scenario being discussed, this would include negotiations with Nova Scotia Power Inc. for the "wheeling" of electricity. It is important to start the negotiations early in the development to allow sufficient time for an agreement to be reached on technical and financial aspects of the project.

Permits and approvals that may be required include the following:

- zoning;
- building permits;
- air and noise emissions;

- waste oil and effluent disposal;
- construction health and safety;
- electrical utility interconnection; and
- property access/easements.

A significant amount of time may be required to obtain all of the necessary permits and approvals.

Contracts for construction of the facility are generally tendered after most of the permits and approvals have been obtained. The business arrangement discussed above may define the responsibilities for construction of the facility. Following completion of construction, once all necessary permits and approvals are in place, the facility is commissioned and put on-line. Long-term operation and maintenance of the plant then begins. The operation of the LFG utilization plant should be closely co-ordinated with the operation of the LFG collection field.

All of Which is Respectfully Submitted,

CONESTOGA-ROVERS & ASSOCIATES

Neil MacDonald, C.E.T.

Eva-Melinda Gorgenyi, B.A.Sc.

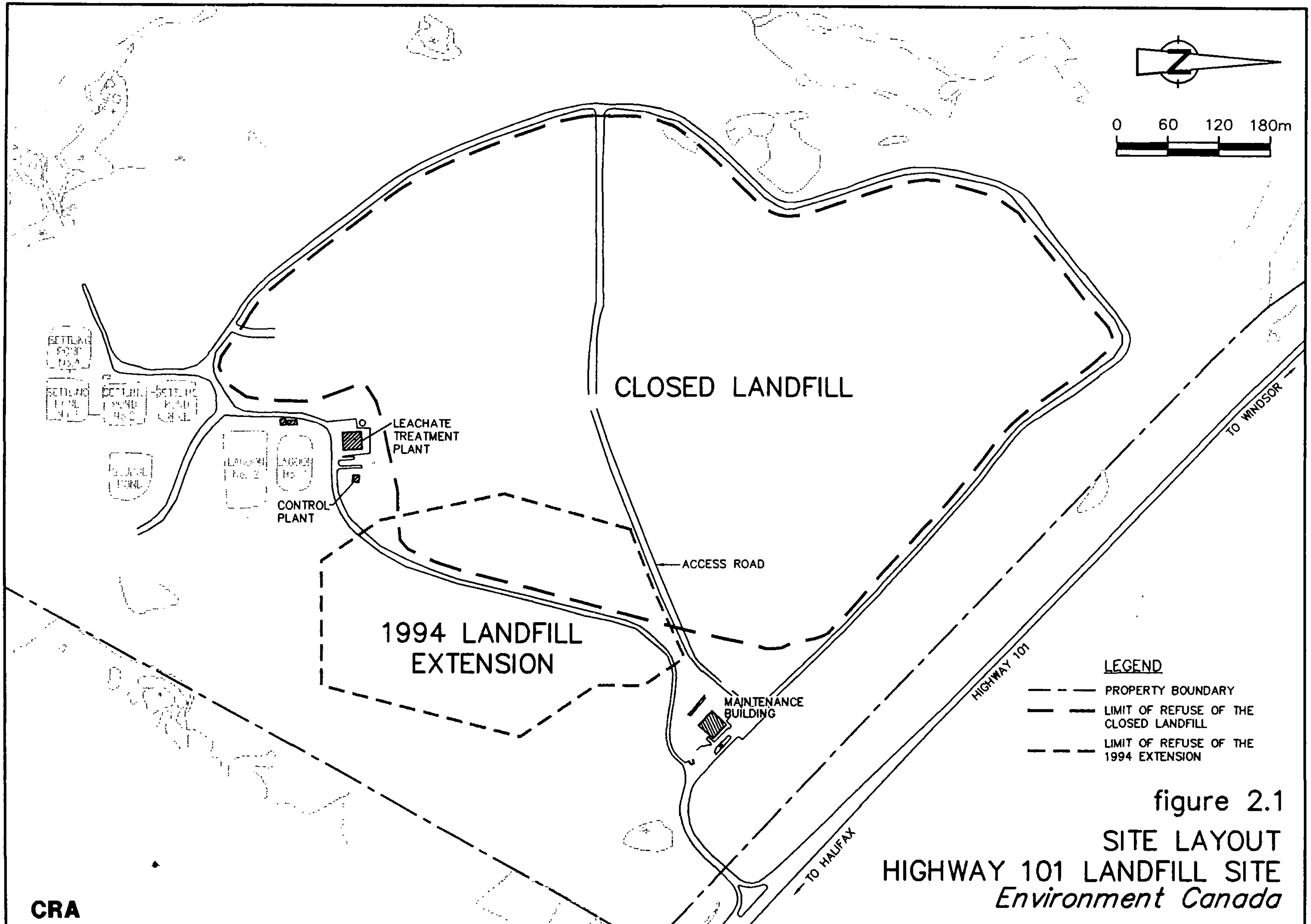


figure 2.1

SITE LAYOUT
HIGHWAY 101 LANDFILL SITE
Environment Canada

8809 (2) DEC 24/96(M) REV.0 (P-01)

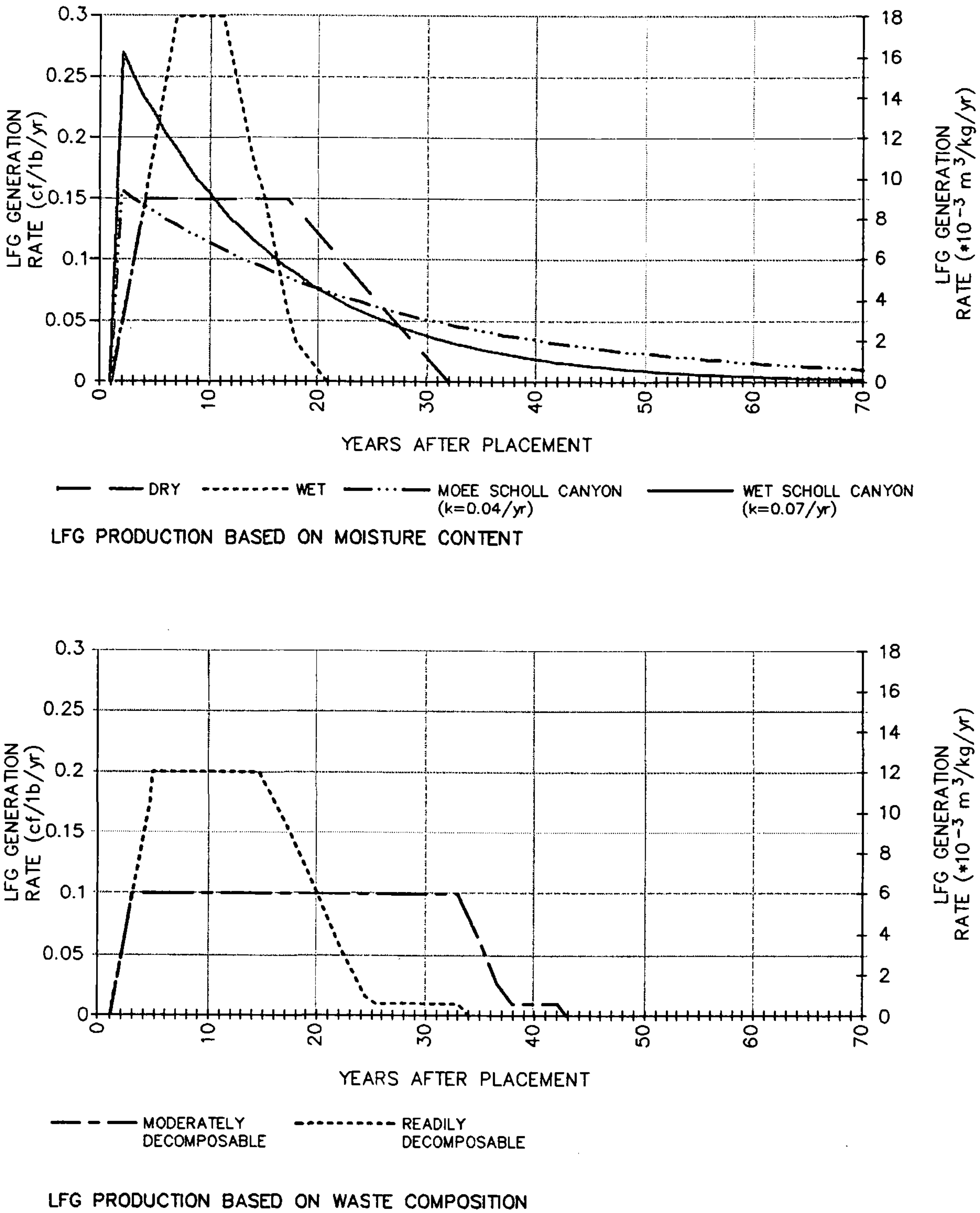


figure 3.1

UNIT LFG GENERATION CURVES
LFG PRODUCTION ASSESSMENT
HIGHWAY 101 LANDFILL SITE
Environment Canada

CRA

8809 (2) DEC 20/96(M) REV.0 (G-02)

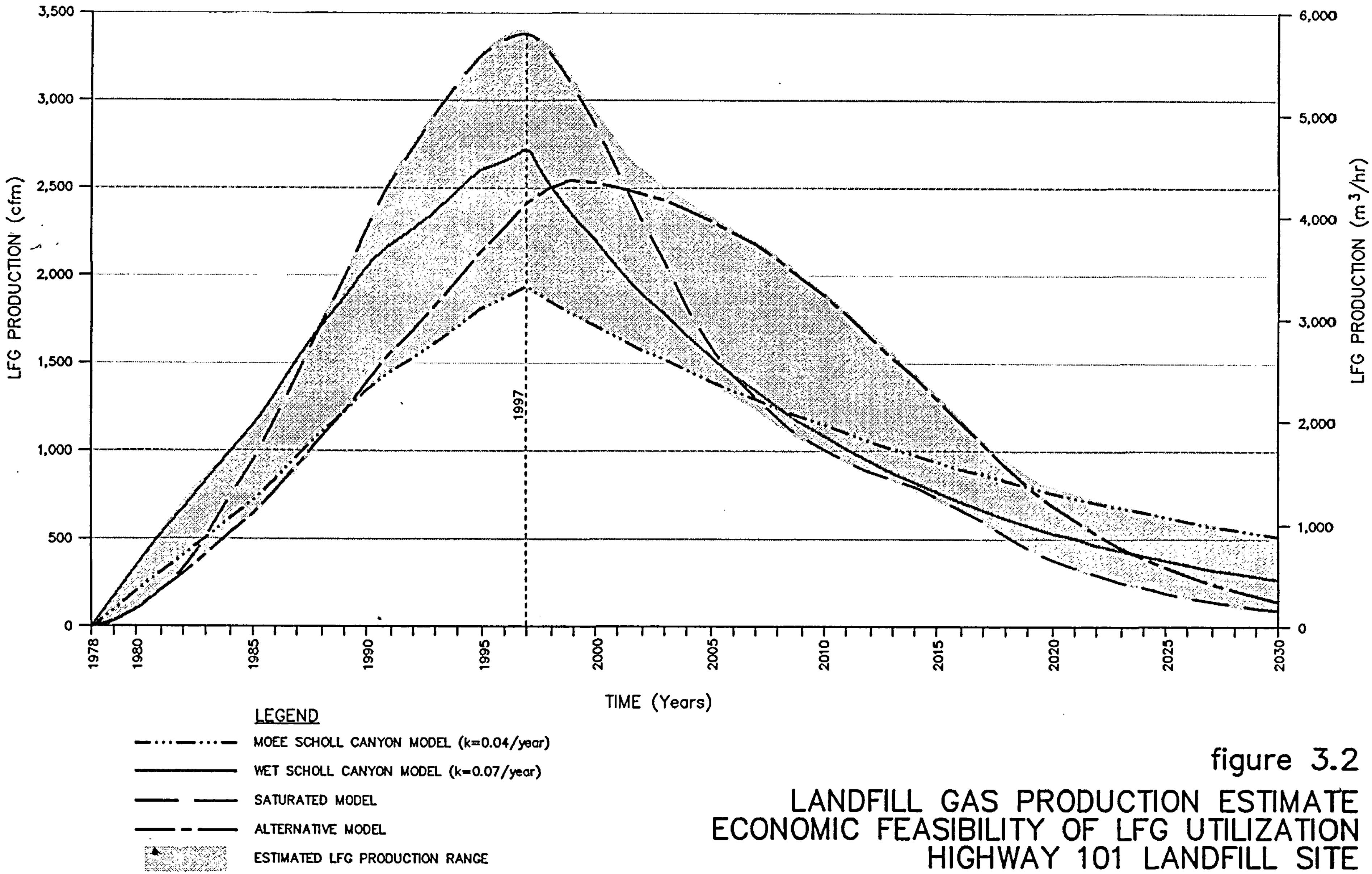


figure 3.2

LANDFILL GAS PRODUCTION ESTIMATE
ECONOMIC FEASIBILITY OF LFG UTILIZATION
HIGHWAY 101 LANDFILL SITE
Environment Canada

CRA

8809 (2) DEC 24/96(M) REV.0 (G-01)

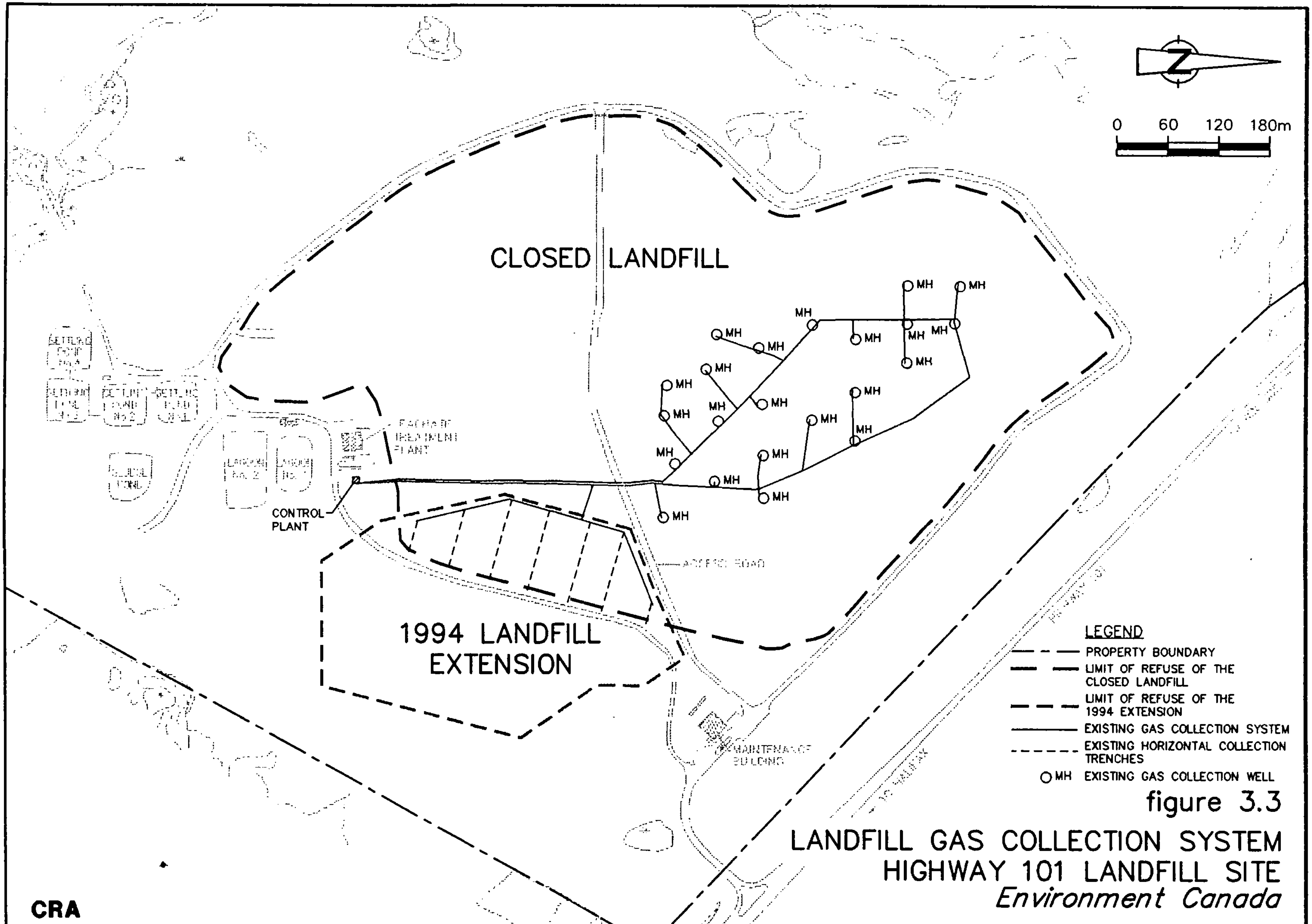
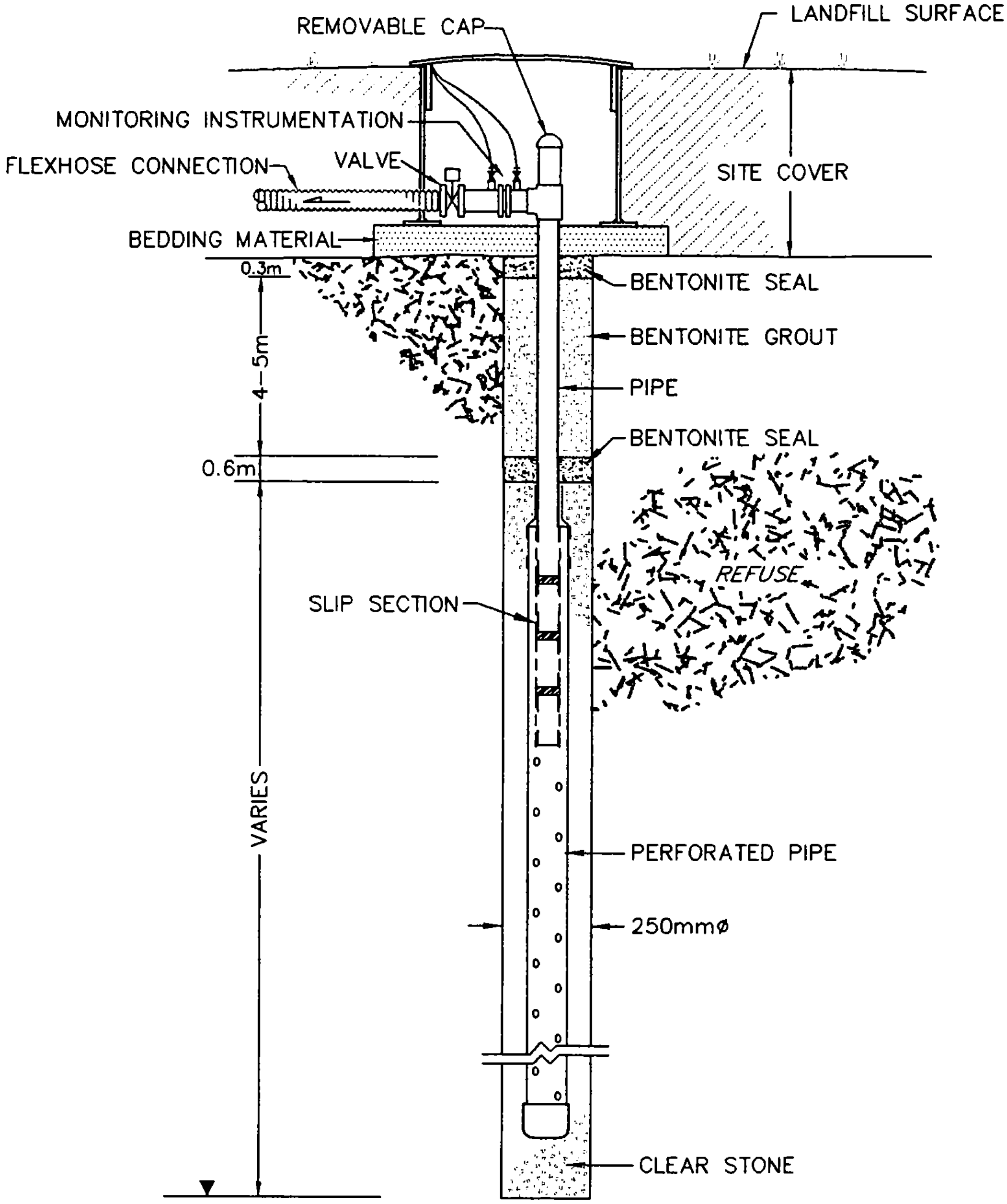


figure 3.3

LANDFILL GAS COLLECTION SYSTEM
HIGHWAY 101 LANDFILL SITE
Environment Canada

8809 (2) DEC 20/96(M) REV.0 (P-02)



INSTALL TO STANDING WATER TABLE OR APPROXIMATELY 3 TO 5m ABOVE THE BASE OF REFUSE, WHICHEVER IS HIGHER.

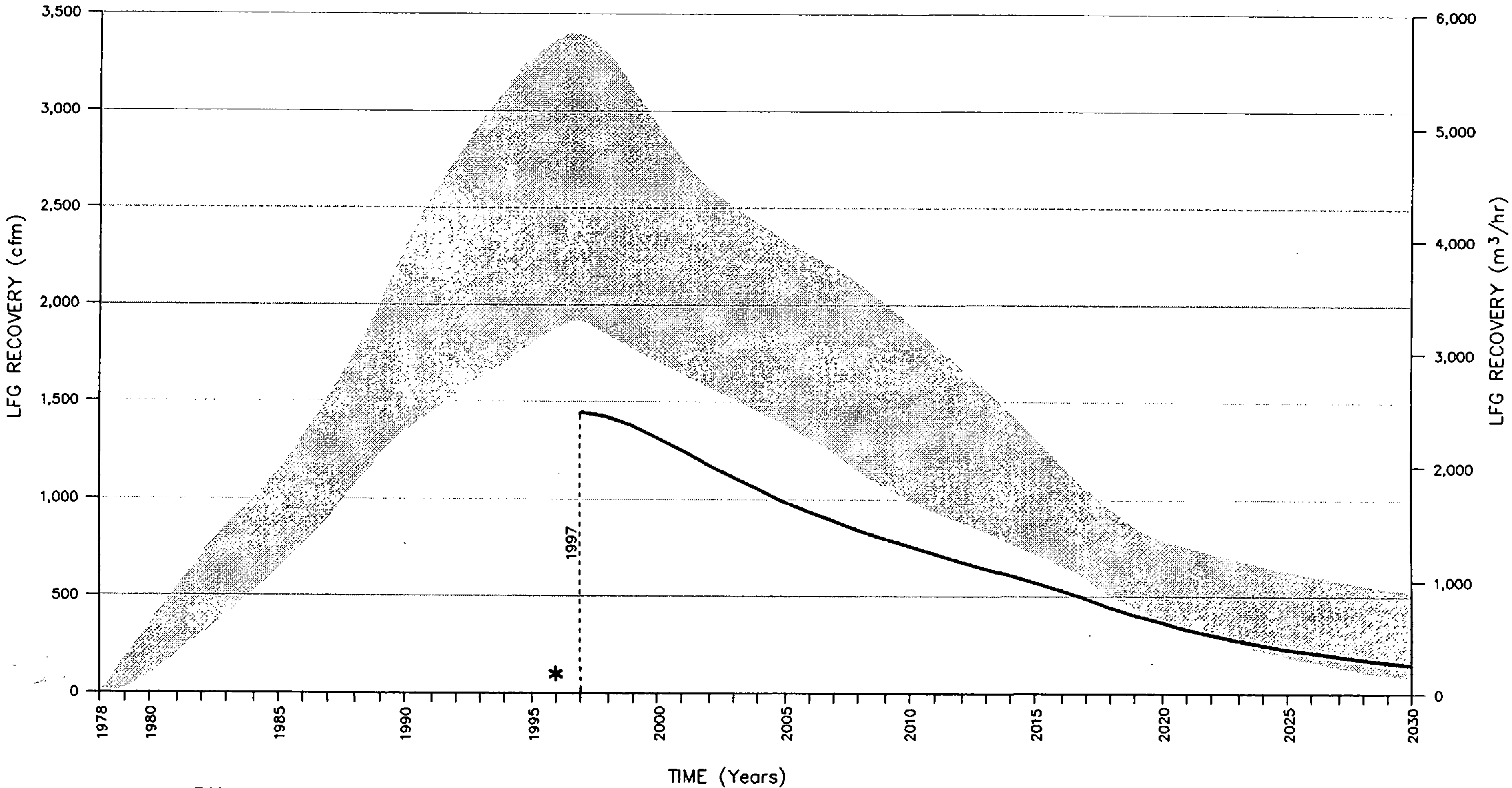
NOT TO SCALE

figure 3.4

TYPICAL LFG EXTRACTION WELL
HIGHWAY 101 LANDFILL SITE
Environment Canada

CRA

8809 (2) DEC 30/96(M) REV.0 (D-01)



LEGEND

ESTIMATED LFG PRODUCTION RANGE

PROJECTED LFG RECOVERY CURVE

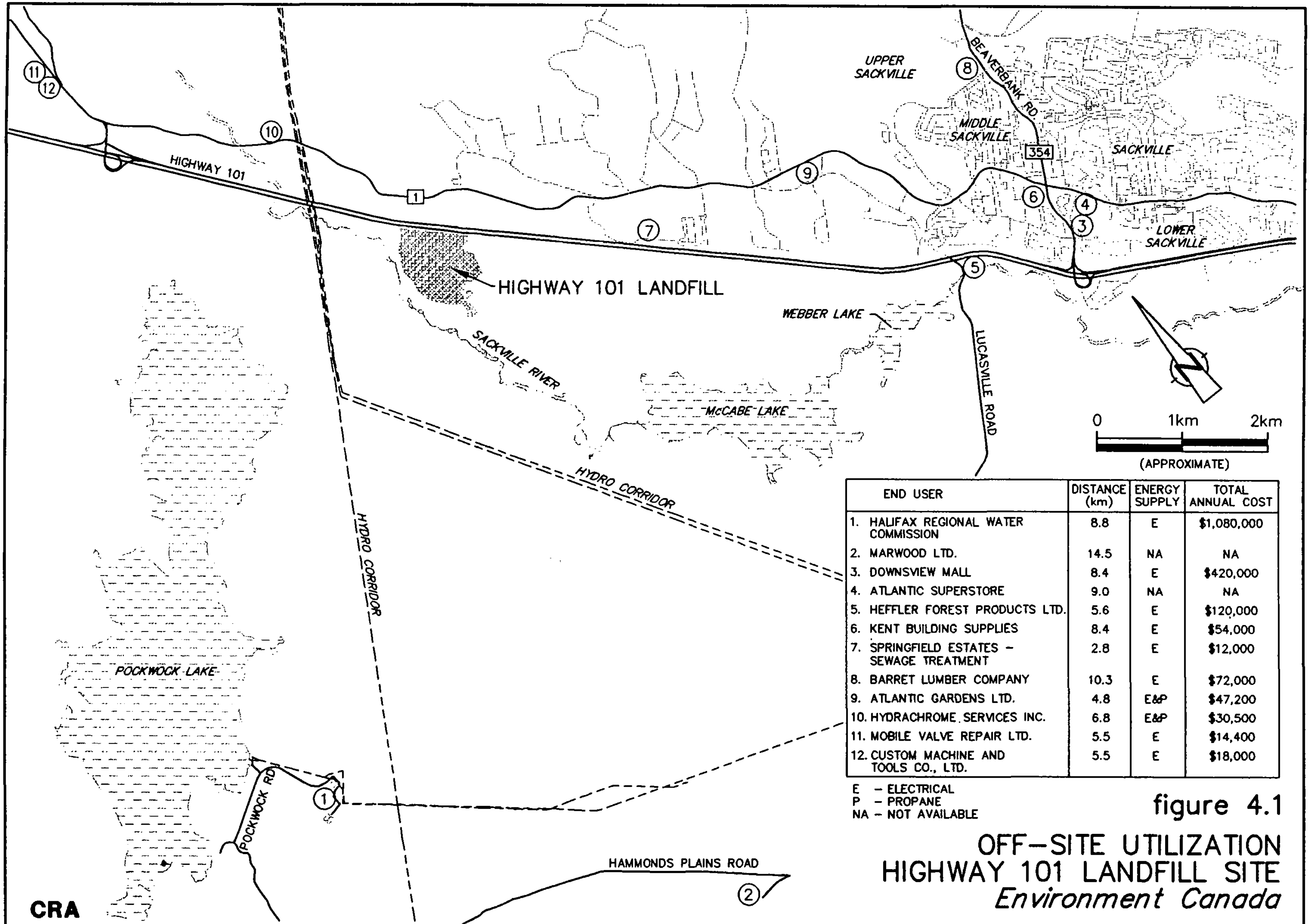
* CURRENT RATE OF LFG RECOVERY (NORMALIZED TO 50% CH_4)

figure 3.5

LANDFILL GAS RECOVERY CURVE
HIGHWAY 101 LANDFILL SITE
Environment Canada

CRA

8809 (2) DEC 24/96(M) REV.0 (G-03)



END USER	DISTANCE (km)	ENERGY SUPPLY	TOTAL ANNUAL COST
1. HALIFAX REGIONAL WATER COMMISSION	8.8	E	$1,080,000
2. MARWOOD LTD.	14.5	NA	NA
3. DOWNSVIEW MALL	8.4	E	$420,000
4. ATLANTIC SUPERSTORE	9.0	NA	NA
5. HEFFLER FOREST PRODUCTS LTD.	5.6	E	$120,000
6. KENT BUILDING SUPPLIES	8.4	E	$54,000
7. SPRINGFIELD ESTATES – SEWAGE TREATMENT	2.8	E	$12,000
8. BARRET LUMBER COMPANY	10.3	E	$72,000
9. ATLANTIC GARDENS LTD.	4.8	E&P	$47,200
10. HYDRACHROME SERVICES INC.	6.8	E&P	$30,500
11. MOBILE VALVE REPAIR LTD.	5.5	E	$14,400
12. CUSTOM MACHINE AND TOOLS CO., LTD.	5.5	E	$18,000

E – ELECTRICAL
P – PROPANE
NA – NOT AVAILABLE

figure 4.1

OFF–SITE UTILIZATION
HIGHWAY 101 LANDFILL SITE
Environment Canada

8809 (2) JAN 21/97(M) REV.0 (P–03)

TABLE 2.1

ANNUAL WASTE TONNAGE
ECONOMIC FEASIBILITY OF LFG UTILIZATION
HIGHWAY 101 LANDFILL

Year	*Total Waste in-place (tonnes)*	*Cummulative Waste in-place (tonnes)*
1978	152,234	152,234
1979	162,388	314,622
1980	166,116	480,738
1981	173,557	654,295
1982	176,151	830,446
1983	183,300	1,013,746
1984	206,479	1,220,225
1985	223,643	1,443,868
1986	250,598	1,694,466
1987	250,401	1,944,867
1988	257,708	2,202,575
1989	266,038	2,468,613
1990	228,787	2,697,400
1991	214,952	2,912,352
1992	222,738	3,135,090
1993	242,952	3,378,042
1994	247,780	3,652,822
1995	208,711	3,834,533
1996 *	208,711	4,043,244

Note:
* - The waste landfilled in 1996 was assumed to be the same tonnage as in 1995.

TABLE 3.1

LFG CONTROL SYSTEM COST COMPARISON
ECONOMIC FEASIBILITY OF LFG UTILIZATION
HIGHWAY 101 LANDFILL SITE
ENVIRONMENT CANADA

Description		*Cost*	*Option 1 LFG Collection Wells*		*Option 2 LFG Collection Trenches*		*Option 3 Geomembrane*		*Option 4 Combined Options 2 and 3* [6]	
			Quantity	*Total*	*Quantity*	*Total*	*Quantity*	*Total*	*Quantity*	*Total*
<u>Older Landfill Area</u>										
Expected Recovery Rate	%		20 - 25		30 - 40		80+		30 - 40	
Modify Existing System	l.s.	allowance		$200,000		$200,000		N/A		$200,000
Well & Wellhead [1]	ea.	$6,500.00	40	$260,000		N/A		N/A		N/A
Trench [2]	m	$70.00		N/A	6,500	$455,000		N/A	6,500	$455,000
Geomembrane [3]	sq.m	$9.50		N/A		N/A	625,000	$5,937,500		N/A
Header	m	$100.00	1,300	$130,000	1,500	$150,000	1,300	$130,000	1,500	$150,000
Lateral	m	$70.00	2,500	$175,000		N/A		N/A		N/A
<u>Life Extension Area</u>										
Expected Recovery Rate	%		50 - 60		50 - 60		80+		80+	
Well & Wellhead	ea.	$6,500.00	15	$97,500	15	$97,500		N/A		N/A
Geomembrane	sq.m	$9.50		N/A		N/A	107,500	$1,021,250	107,500	$1,021,250
Header [4]	m	$100.00	500	$50,000	500	$50,000	400	$40,000	400	$40,000
Lateral	m	$70.00	1,000	$70,000	1,000	$70,000		N/A		N/A
Contingency	%	10		$98,250		$102,250		$712,875		$186,625
Total Capital Costs				**$1,030,750**		**$1,074,750**		**$7,801,625**		**$2,012,875**
Annual O&M [5]				$80,000-$100,000		$60,000-$80,000		$25,000-$30,000		$50,000-$60,000

<u>Notes:</u>
All items supplied and installed. Engineering fees and applicable taxes are extra.
(1) Installation of shallow wells. Wellhead includes valves, fittings, chamber and cover. The number of wells is limited by existing high liquid levels within the refuse.
(2) Trench spacing 25 metres. Trench installation was limited to areas of the Site with more than 1 metre of waste above the leachate level.
(3) Includes the installation of 150mm perforated, corrugated pipes, embedded in gravel, in a grid layout, 50 metres apart, covered with a geomembrane liner, 0.3 metres under the ground surface and the placement of topsoil and seeding and mulching.
(4) Installation of a header is included in the header installation for the older landfill area.
(5) Includes system operation, inspections, monitoring and routine maintenance.
(6) Use of horizontal trenches (Option 2) on older landfill area and geomembrane (Option 3) on landfill extension area.

TABLE 4.1

WHEELING OF ELECTRICAL POWER - SCENARIO 1
ECONOMIC FEASIBILITY OF LFG UTILIZATION
HIGHWAY 101 LANDFILL SITE
ENVIRONMENT CANADA

Capital Cost (1000's)		Annual Operating Cost		Assumptions		Electricity	
Gas Treatment	$750	O&M Cost ($/kWh)	0.018	Gross Unit Capacity	1135 kW		
Mechanical/Electrical/Civil	$1,200	Financing (1000's)	$1,371	Net Unit Capacity	1090 kW	Savings	0.065 $/kWh
Eng/Gen Unit (4 sets)	$2,800			Availability	98%	Wheeling Fee	0.01 $/kWh
				Conversion Efficiency	36%		
		Annual Savings		LFG Btu/scf	450		
Total	$4,750	Boiler Fuel (1000's)	$40	Inflation	2%		
				Rate of Financing	6%		
				Amortization (years)	4		

Year	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Estimated LFG Recovery (cfm)	1830	1792	1726	1641	1554	1467	1380	1296	1219	1149	1085	1025	967	913	860	810	761	714	669	618	566
Electrical Generation Potential (kW)		5103	4914	4674	4426	4178	3929	3691	3473	3273	3090	2918	2755	2601	2450	2306	2168	2033	1905	1761	1611
No. of units		4	4	4	4	3	3	3	3	2	2	2	2	2	2	2	2	1	1	1	1
Gross Electrical Generation (kW)		4540	4540	4540	4540	3405	3405	3405	3405	2270	2270	2270	2270	2270	2270	2270	2270	1135	1135	1135	1135
Net Electrical Generation (kW)		4271	4271	4271	4271	3203	3203	3203	3203	2136	2136	2136	2136	2136	2136	2136	2136	1068	1068	1068	1068
Annual Capital Cost (1000's)		($1,371)	($1,371)	($1,371)	($1,371)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Annual Operating Cost (1000's)		($1,030)	($1,030)	($1,030)	($1,030)	($768)	($768)	($768)	($768)	($506)	($506)	($506)	($506)	($506)	($506)	($506)	($506)	($244)	($244)	($244)	($244)
Annual Savings (1000's)		$2,432	$2,432	$2,432	$2,432	$1,824	$1,824	$1,824	$1,824	$1,216	$1,216	$1,216	$1,216	$1,216	$1,216	$1,216	$1,216	$608	$608	$608	$608
Revenue (1000's)		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Net (1000's)		$31	$31	$31	$31	$1,056	$1,056	$1,056	$1,056	$710	$710	$710	$710	$710	$710	$710	$710	$364	$364	$364	$364

Net Present Value (NPV) (1997) **$14,314**

Notes:
Scenario 1 assumes 70% gas recovery from the Site.(Collection field Option 3).
200 kWh used for the leachate treatment plant.

7

TABLE 4.2

WHEELING OF ELECTRICAL POWER - SCENARIO 1A
ECONOMIC FEASIBILITY OF LFG UTILIZATION
HIGHWAY 101 LANDFILL SITE
ENVIRONMENT CANADA

Capital Cost (1000's)	
Gas Treatment	$650
Mechanical/Electrical/Civil	$950
Eng/Gen Unit (3 sets)	$1,950
Total	$3,550

Annual Operating Cost	
O&M Cost ($/kWh)	0.018
Financing (1000's)	$482
Annual Savings	
Boiler Fuel (1000's)	$40

Assumptions	
Gross Unit Capacity	600 kW
Net Unit Capacity	576 kW
Availability	98%
Conversion Efficiency	36%
LFG Btu/scf	450
Inflation	2%
Rate of Financing	6%
Amortization (years)	10

Electricity	
Savings	0.065 $/kWh
Wheeling Fee	0.01 $/kWh

Year	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Estimated LFG Recovery (cfm)	1002	1000	975	932	888	844	801	760	722	687	655	624	596	569	543	517	494	470	448	419	386
Electrical Generation Potential (kW)		2848	2777	2654	2529	2405	2281	2164	2055	1956	1864	1778	1697	1620	1545	1474	1405	1339	1276	1193	1099
No. of units		3	3	3	3	3	3	3	3	3	3	2	2	2	2	2	2	2	2	2	1
Gross Electrical Generation (kW)		1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1200	1200	1200	1200	1200	1200	1200	1200	1200	600
Net Electrical Generation (kW)		1693	1693	1693	1693	1693	1693	1693	1693	1693	1693	1129	1129	1129	1129	1129	1129	1129	1129	1129	564
Annual Capital Cost (1000's)		($482)	($482)	($482)	($482)	($482)	($482)	($482)	($482)	($482)	($482)	--	--	--	--	--	--	--	--	--	--
Annual Operating Cost (1000's)		($398)	($398)	($398)	($398)	($398)	($398)	($398)	($398)	($398)	($398)	($259)	($259)	($259)	($259)	($259)	($259)	($259)	($259)	($259)	($121)
Annual Savings (1000's)		$964	$964	$964	$964	$964	$964	$964	$964	$964	$964	$643	$643	$643	$643	$643	$643	$643	$643	$643	$321
Revenue (1000's)		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Net (1000's)		$84	$84	$84	$84	$84	$84	$84	$84	$84	$84	$383	$383	$383	$383	$383	$383	$383	$383	$383	$200

Net Present Value (NPV) (1997) $5,887

Notes:
Scenario 1A assumes 30% gas recovery from the older portion of the Site and 80% gas recovery from the life expansion area.(Collection field Option 4).
200 kWh used for the leachate treatment plant.

TABLE 4.3

SALE OF ELECTRICAL POWER - SCENARIO 2
ECONOMIC FEASIBILITY OF LFG UTILIZATION
HIGHWAY 101 LANDFILL SITE
ENVIRONMENT CANADA

Capital Cost (1000's)	
Gas Treatment	$750
Mechanical/Electrical/Civil	$1,200
Eng/Gen Unit (4 sets)	$2,800
Total	$4,750

Annual Operating Cost	
O&M Cost ($/kWh)	0.018
Financing (1000's)	$414
Annual Savings	
Boiler Fuel (1000's)	$40

Assumptions	
Gross Unit Capacity	1135 kW
Net Unit Capacity	1090 kW
Availability	98%
Conversion Efficiency	36%
LFG Btu/scf	450
Inflation	2%
Rate of Financing	6%
Amortization (years)	20

Electricity	
Cost	0.03 $/kWh
Savings	0.065 $/kWh
Wheeling Fee	0.01 $/kWh

Year	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Estimated LFG Recovery (cfm)	1830	1792	1726	1641	1554	1467	1380	1296	1219	1149	1085	1025	967	913	860	810	761	714	669	618	566
Electrical Generation Potential (kW)		5103	4914	4674	4426	4178	3929	3691	3473	3273	3090	2918	2755	2601	2450	2306	2168	2033	1905	1761	1611
No. of units		4	4	4	4	3	3	3	3	2	2	2	2	2	2	2	2	1	1	1	1
Gross Electrical Generation (kW)		4540	4540	4540	4540	3405	3405	3405	3405	2270	2270	2270	2270	2270	2270	2270	2270	1135	1135	1135	1135
Net Electrical Generation (kW)		4271	4271	4271	4271	3203	3203	3203	3203	2136	2136	2136	2136	2136	2136	2136	2136	1068	1068	1068	1068
Annual Capital Cost (1000's)		($414)	($414)	($414)	($414)	($414)	($414)	($414)	($414)	($414)	($414)	($414)	($414)	($414)	($414)	($414)	($414)	($414)	($414)	($414)	($414)
Annual Operating Cost (1000's)		($716)	($716)	($716)	($716)	($537)	($537)	($537)	($537)	($358)	($358)	($358)	($358)	($358)	($358)	($358)	($358)	($179)	($179)	($179)	($179)
Annual Savings (1000's)		$114	$114	$114	$114	$114	$114	$114	$114	$114	$114	$114	$114	$114	$114	$114	$114	$114	$114	$114	$114
Revenue (1000's)		$1,141	$1,141	$1,141	$1,141	$842	$842	$842	$842	$544	$544	$544	$544	$544	$544	$544	$544	$246	$246	$246	$246
Net (1000's)		$124	$124	$124	$124	$5	$5	$5	$5	($114)	($114)	($114)	($114)	($114)	($114)	($114)	($114)	($233)	($233)	($233)	($233)
Net Present Value (NPV) (1997)	**($1,972)**																				

Notes:

Scenario 2 assumes 70% gas recovery from the Site.(Collection field Option 3).

200 kWh used for the leachate treatment plant.

TABLE 4.4

SALE OF ELECTRICAL POWER - SCENARIO 2A
ECONOMIC FEASIBILITY OF LFG UTILIZATION
HIGHWAY 101 LANDFILL SITE
ENVIRONMENT CANADA

apital Cost (1000's)		Annual Operating Cost		Assumptions		Electricity	
as Treatment	$650	O&M Cost ($/kWh)	0.018	Gross Unit Capacity	1135 kW	Cost	0.03 $/kWh
lechanical/Electrical/Civil	$950	Financing (1000's)	$209	Net Unit Capacity	1090 kW	Savings	0.065 $/kWh
ng/Gen Unit (1 set)	$800			Availability	95%	Wheeling Fee	0.01 $/kWh
				Conversion Efficiency	36%		
		Annual Savings		LFG Btu/scf	450		
otal	$2,400	Boiler Fuel (1000's)	$40	Inflation	2%		
				Rate of Financing	6%		
				Amortization (years)	20		

ear	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
stimated LFG Recovery (cfm)	1002	1000	975	932	888	844	801	760	722	687	655	624	596	569	543	517	494	470	448	419	386
lectrical Generation Potential (kW)		2848	2777	2654	2529	2405	2281	2164	2055	1956	1864	1778	1697	1620	1545	1474	1405	1339	1276	1193	1099
o. of units		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
ross Electrical Generation (kW)		1135	1135	1135	1135	1135	1135	1135	1135	1135	1135	1135	1135	1135	1135	1135	1135	1135	1135	1135	1135
et Electrical Generation (kW)		1035	1035	1035	1035	1035	1035	1035	1035	1035	1035	1035	1035	1035	1035	1035	1035	1035	1035	1035	1035
nnual Capital Cost (1000's)		($209)	($209)	($209)	($209)	($209)	($209)	($209)	($209)	($209)	($209)	($209)	($209)	($209)	($209)	($209)	($209)	($209)	($209)	($209)	($209)
nnual Operating Cost (1000's)		($163)	($163)	($163)	($163)	($163)	($163)	($163)	($163)	($163)	($163)	($163)	($163)	($163)	($163)	($163)	($163)	($163)	($163)	($163)	($163)
nnual Savings (1000's)		$114	$114	$114	$114	$114	$114	$114	$114	$114	$114	$114	$114	$114	$114	$114	$114	$114	$114	$114	$114
evenue (1000's)		$219	$219	$219	$219	$219	$219	$219	$219	$219	$219	$219	$219	$219	$219	$219	$219	$219	$219	$219	$219
et (1000's)		($39)	($39)	($39)	($39)	($39)	($39)	($39)	($39)	($39)	($39)	($39)	($39)	($39)	($39)	($39)	($39)	($39)	($39)	($39)	($39)

et Present Value (NPV) (1997) **($969)**

otes:
cenario 2A assumes 30% gas recovery from the older portion of the Site and 80% gas recovery from the life expansion area.(Collection field Option 4).
)0 kWh used for the leachate treatment plant.