LANDFILL GAS POTENTIAL ASSESSMENT REPORT
LINGSHAN LANDFILL, QUINGDAO, CHINA
EPA Contract XA-83397501-0

Submitted to:

Rachel Goldstein
Landfill Methane Outreach Program
Environmental Protection Agency
1200 Pennsylvania Avenue, NW
Washington, DC 20460

Prepared for:

Mr. Xu Haiyun
Environmental Sanitation Engineering Technology Research Center (ESETRC)
No. 3, Huixinli Chaoyang District
Beijing, P.R. China 100029

Prepared by:

GC Environmental, Inc.
1230 N. Jefferson Suite J
Anaheim, California  92807

March 1, 2011
TABLE OF CONTENT

EXECUTIVE SUMMARY ............................................................................................................. 1
1. INTRODUCTION ................................................................................................................ .. 2
2. LANDFILL GAS................................................................................................................ .... 2
3. LINGSHAN LANDFILL INFORMATION........................................................................... 4
  3.1 Landfill Location and Operation.............................................................................. 4
  3.2 Environmental Data ................................................................................................. 5
  3.3 Base Liner, and Cover.............................................................................................. 5
  3.4 Waste Depth............................................................................................................. 5
  3.5 Waste Placement/ Final Cover .............................................................................. 5
  3.6 Landfill Capacity/ Waste Inputs .............................................................................. 5
  3.7 Waste Composition.................................................................................................. 7
4. GAS AND LEACHATE ......................................................................................................... 7
  4.1 Leachate ................................................................................................................... 7
  4.2 Landfill Gas ............................................................................................................. 8
5. LANDFILL GAS MODELING.............................................................................................. 8
6. RESULTS OF LANDFILL GAS MODEL ........................................................................... 10
7. LFG COLLECTION EFFICIENCY ..................................................................................... 11
8. AVAILABLE THERMAL ENERGY .................................................................................. 12
9. EMISSION REDUCTION ESTIMATION .......................................................................... 14
10. OUTLINE SPECIFICATION OF A GAS EXTRACTION SYSTEM ............................. 16
11. FINANCE MODEL .............................................................................................................. 18
  11.1 Medium BTU Fuel................................................................................................. 18
  11.2 Power Generation................................................................................................... 18
  11.3 Small Engines/Power Production .......................................................................... 19
  11.4 Financial Model Summary..................................................................................... 19
12. CONCLUSIONS ................................................................................................................ ... 20

LIST OF THE TABLES AND FIGURES

TABLES

Table 1 – Waste Input 2003 - 2008 .......................................................................................... 6
Table 2 –Estimated Waste Input 2009 – 2028 ......................................................................... 6
Table 3 – Gas Measurements .................................................................................................... 8
Table 4 – Methane generation rate (k) and generation potential (Lo) ...................................... 10
Table 5 – China Landfill Gas Model Results (@50% CH₄, 64% collection efficiency) ............. 12
Table 6 – Estimated Landfill Gas Available Thermal Energy .................................................. 13
Table 7 – Estimated Available Emission Reductions ................................................................. 15
Table 8 – Summary of $LFGcost$ Results ............................................................................. 19
FIGURES

Figure 1 – Landfill Gas Emissions .................................................................................................................. 11
Figure 2 – Internal Rate of Return of Alternatives ......................................................................................... 20

APPENDICES

Appendix I Certificate of GA 2000 Calibration
Appendix II Direct Use Project Economics
Appendix III Engine Power Production Project Economics
Appendix IV Small Engine Power Production Project Economics
Appendix V Site Location and Selected Photos
PROJECT CONDITIONS/ LIMITATIONS

This report has been prepared for as part of the Methane to Markets Partnership program and is public information.

The information and predictions contained within this assessment report are based on the data provided by the site owners and operators. Neither the U.S. EPA nor its contractors can take responsibility for the accuracy of this data. Measurements, assessments, and predictions presented in this report are based on the data and physical conditions of the landfill observed at the time of the site visit.

*LFGcost* is a landfill gas energy project cost estimating tool developed for EPA's LMOP. *LFGcost* estimates landfill gas generation rates using a first-order decay equation. This equation is used to estimate generation potential but cannot be considered an absolute predictor of the rate of landfill gas generation. Variations in the rate and types of incoming waste, site operating conditions, and moisture and temperature conditions may provide substantial variations in the actual rates of generation.

The costs that are estimated by *LFGcost* are based on typical project designs and for typical landfill situations. The model attempts to include all equipment, site work, permits, operating activities, and maintenance that would normally be required for constructing and operating a typical project. However, individual landfills may require unique design modifications, which would add to the cost estimated by *LFGcost*.

Analyses performed using *LFGcost* are considered preliminary and should be used for guidance only. A detailed final feasibility assessment should be conducted by qualified landfill gas professionals prior to preparing a system design, initiating construction, purchasing materials, or entering into agreements to provide or purchase energy from a landfill gas project.

The Lingshan landfill site currently passively vents gas. The site has not yet implemented a gas collection, flaring or utilization system. The capital and O&M costs, return on investment and net present value resulting from installing such a system at the Lingshan landfill site are estimated with the U.S. EPA *LFGcost* Model that is based on typical costs in the United States. Appropriate user inputs and a number of adjustments to the model were used to make results approximate the costs and revenues in China, but no warranty is given or implied on the accuracy of these US and Chinese data.

While due care and attention has been given to development of this report, potential investors in landfill gas utilization projects at Lingshan landfill are advised to satisfy themselves as to the accuracy of the data and predictions contained in this report.
EXECUTIVE SUMMARY

The Lingshan Landfill (landfill) is located at the north bound of Lingshan Town, Jimo City, Shandong Province, China. The landfill is owned and operated by the Jimo Urban - Rural Construction Bureau. The landfill covers a total area of 28.7 hectare, with a total design capacity of 3.79 million cubic meters of waste. The landfill was designed with 3 phases. Phase I and the leachate treatment area are located at the north end of the property, and Phases II and III are located south of Phase I, with an office located at the southwest corner of the property. Phase I occupies an area of 5.5 hectare and it is currently active receiving municipal waste from Jimo City. Filling of Phase I landfill started on May 1, 2003. The anticipated closure date for all phases is 2028. An assessment by the China Association of Urban Environmental Sanitation (CAUES) classified the landfill as Grade I in year 2006.

Under a grant from the United States Environmental Protection Agency (U.S. EPA), the China Environmental Sanitation Engineering Technology (ESETRC) and GC Environmental, Inc. (GCE) visited the landfill and completed an initial assessment of the landfill's potential to generate methane for beneficial use. Analysis of the data provided by the former landfill manager and Jimo City Landscape Management Bureau, and our observation during the site visit, indicates that the site could be currently emitting 298 standard cubic feet per minute (SCFM, 507 m³/hr) of landfill gas, containing approximately 50% methane. This rate could reach a peak of approximately 841 SCFM (1,430 m³/hr) in 2029. However, due to the current construction techniques and materials employed at the site, not all landfill gas will be available for collection and utilization. Using the landfill operational information provided by the landfill representatives, and our observations during the site visit, a 64% collection efficiency was estimated by the US EPA’s China Landfill Gas Model (v1.1, March, 2009), the amount of landfill gas that could be collected for beneficial use currently is 191 SCFM (324 m³/hr), and will peak at 538 SCFM (915 m³/hr) in 2029. This is intended to be a realistic and conservatively low estimate of recoverable gas. However, this amount is low for the volume of refuse that will potentially be deposited in the landfill. There may be several reasons for the low volume of gas. One reason could be that waste may not be highly compacted and covered with intermediate cover. This appears to be indicated by the volume of leachate generated at the landfill, which is close to the mean annual precipitation times the Phase 1 surface area, indicating that waste acts as a sieve and does not retain the moisture. In addition high oxygen contents measured at most of the vent wells in Phase I indicates an aerobic environment in the area of the wells. Air can readily infiltrate the landfill if waste is either not covered or it is covered with loosely fitting HDPE cover that is sewn together and therefore does not inhibit air infiltration into waste. Landfill gas volume would increase with enhancement of effective solid waste management practices. These measures would also help achieve reasonable levels of collection efficiency necessary for a successful energy project.

Landfill gas generation modeling in this assessment report indicates that the Lingshan landfill produces a moderate and steadily increasing amount of LFG. However, project development does not appear to be economical at this time for multiple reasons. First and foremost, there is no nearby user for direct fuel use, which is the most economical solution for this project, unless the landfill owner opts to use the fuel for onsite power use. Second, based on the result provided by
LFGcost program, greenhouse gas emission reduction credits will be required for a project to work. With the current world wide financial situation, the market for greenhouse gas emission reduction credits is down, but this is not expected to last. In the mean time, improved solid waste management practices could be implemented in preparation for project development.

An economic evaluation of direct use for the Lingshan landfill has been included should in the future this option be applicable by industry locating near the landfill, and/ or the landfill owner opts to use fuel for onsite utility.

1. INTRODUCTION

The U.S. Environmental Protection Agency (U.S. EPA) is working in conjunction with the China National Development and Reform Commission (NDRC), at the Steering Committee level of the Methane to Markets Partnership, on a cooperative program to promote the beneficial use of landfill methane, while also reducing landfill methane emissions to the atmosphere. Some of the key activities of this cooperative program include identifying suitable landfills with sufficient quantities of high methane quality gas that can be used to meet local energy needs, preparing assessment reports, and possibly training on landfill gas to energy projects. To support these activities, the U.S. EPA has contracted with the team of China Environmental Sanitation Engineering Technology and GC Environmental, Inc. to evaluate the Lingshan landfill.

An important part of identifying good candidate landfills for energy projects involves conducting site visits at landfills that have been pre-screened and identified as having the potential for energy project development. ESETRC and GCE visited Lingshan landfill located north of the Jimo City, Shan Dong Province, China in July 2010 to collect information on landfill design, waste volume, waste composition and gas composition, and make observations to assess the gas generation and energy recovery potential of the landfill sites. The site visit included collecting information on the landfill site history and landfilling operations, and a “walk over” and visual inspection of the topography and general condition / operation of the landfill. Physical work on the site was limited to analysis of gas samples collected from the vent wells in the Phase I area, using a portable gas analyzer. Information was also sought on nearby potential energy users that may be interested in using the energy produced by the landfill.

This assessment report summarizes the findings of the site visit including a brief assessment of the gas potential of the landfill and examines the opportunities that may exist for using the landfill gas to meet the energy needs of local utilities or industries. This report also includes technical information that will be helpful to potential LFG project developers as they assess the viability of a landfill gas energy recovery project.

2. LANDFILL GAS

Landfill gas is generated as a result of anaerobic decomposition of organic waste in the landfill. Landfill gas is composed of approximately 55-60 percent methane and 40-45 percent carbon...
dioxide, with a small amount of oxygen, nitrogen, water vapor, and trace concentrations of volatile organic compounds (VOCs) including some hazardous air pollutants (HAPs). Both methane and carbon dioxide are greenhouse gases (GHG) with potential to contribute to global warming. Because of its higher absorption capacity for infrared, methane is a more potent GHG than carbon dioxide with a global warming potential over 21 times that of CO2. Since the Intergovernmental Panel on Climate Change (IPCC) does not consider the carbon dioxide specifically present in raw landfill gas to be a GHG (landfill generated CO2 is considered to be "biogenic" and thus, part of the natural carbon cycle), only the methane content of the gas is included in calculations of atmospheric GHG emissions.

As landfill gas is generated, gas pressure in the landfill increases. For an ideal gas, the pressure is directly proportional to the number of gas molecules in a given volume. Each molecule of cellulose produces six molecules of gas. Cellulose is the most abundant putrescible waste in landfills. The anaerobic decomposition of cellulose is as follows:

\[
\text{C}_6\text{H}_{10}\text{O}_5 + \text{H}_2\text{O} \xrightarrow{\text{Anaerobic Bacteria}} 3\text{CH}_4(\text{g}) + 3\text{CO}_2(\text{g}).
\]

Therefore, a pressure gradient will form in the landfill caused by the reduction in solids volume and the increase in the gas volume. This in turn pushes gas from the landfill (convective flow). Landfill gas also moves by diffusion, or concentration gradient. As landfill gas is produced, there will be high concentrations of CO2 and CH4 in the landfill, and high concentrations of air (O2 and N2) outside the landfill. Diffusion will move LF G outside the landfill and air inward. This migration will stop when gas concentrations inside and outside the landfill are equal. As the air outside the landfill is an infinite sink, this will never occur. However, below the landfill the soil gas concentration will tend to reach concentrations similar to the gas in the landfill.

Landfill gas moves by migration into the adjacent subsurface soil, and by venting through the landfill cover system to the atmosphere. A common method for controlling landfill gas emissions is to install a landfill gas collection system that extracts landfill gas under the influence of a small vacuum and combustion of methane in a flare, an engine generator or other devices.

Therefore, the landfill gas collection and control results in a substantial net reduction of GHG emissions by converting the methane to carbon dioxide and water. Additional benefits beyond GHG emission reductions include the potential for improvement in local air quality through the destruction of HAPs and VOCs through landfill gas combustion.

Good quality landfill gas (high methane content with low oxygen and nitrogen levels) can be utilized as a fuel to offset the use of conventional fossil fuels or other fuel types. The heating value typically ranges from 400 Btu to 500 Btu per cubic feet, which is approximately one half the heating value of natural gas. Existing and potential uses of landfill gas generally fall into one of the following categories: electrical generation, direct use for heating/boiler fuel (medium-Btu), upgrade to high Btu gas, and other uses such as vehicle fuel.
This study focuses on evaluation of potential use of landfill gas for electrical generation and direct use projects at the Lingshan landfill. A high BTU gas project is not considered feasible because the rate of methane generation is not sufficient to support the high capital cost of this type of facility.

3. LINGSHAN LANDFILL INFORMATION

A site visit was performed on July 20, 2010. In attendance were; Mr. Sun Wei-min, the landfill manager, Mr. Jiang Fu-shan, the former department head of Jimo City Landscape Management Bureau, Mr. Haiyun Xu of ESETRC, Ms. Farideh Kia of GCE, and Mr. Jason Leung of OWThk, GCE’s contractor. The following provides a summary of the information/data obtained for the Lingshan landfill.

3.1 Landfill Location and Operation

The landfill is located on the north of Lingshan Town, about 15 km from the Jimo City downtown, Shandong Province, China. The landfill is owned and operated by the Jimo Urban-Rural Construction Bureau. The landfill is surrounded by farming communities, and crop land.

The overall landfill covers a total area of 28.7 hectare, with a total design capacity of 3.79 million cubic meters of waste. The landfill was designed with three (3) phases. The construction of the site was approved in November 2001. The feasibility study and basis of design was done by Qingdao Environmental Hygiene Research Institute. The active Phase I landfill, and the leachate treatment system are located on north side of the property, and future Phases II and III are located south of Phase I, with an office located at the southwest corner of the landfill property. Phase I occupies an area of 5.5 hectare and it is currently receiving municipal waste from Jimo City (2002 data: population of 1.08 M) and the surrounding area. Filling of Phase I landfill started on May 1, 2003. The estimated closure date for all three phases of the landfill is 2028; however this date is not confirmed and depends on the development progress of Phase II area. In 2006, the landfill was classified as Grade I landfill, based on an assessment by China Association of Urban Environmental Sanitation (CAUES).

There was no gas collection system at the landfill during our site visit on July 20, 2010. There were nine (9) passive vent wells in the Phase I area. During our site visit, seven of the vent wells were monitored. Of the seven wells, one well was located within fresh waste, and the rest were in older waste that had been covered with the sewn HDPE cover. Two of the wells were not monitored because of the wet/slippery ground due to the heavy rain.

The landfill operates 12 hours per day (5:00 A.M. to 5:00 p.m.), 7 days a week. No compactor was on site on July 20, 2010. Two bulldozers were observed.

Based on the information provided, there has been no report of landfill fire at the Lingshan landfill.
Currently, Shandong Shifang Environmental Protection and Bio-energy is conducting an investigation to convert LFG to liquefied natural gas (LNG). Another Beijing company is also investigating the potential energy development project on site. At the time of our site visit, there was no potential medium BTU LFG user close to the landfill.

3.2 Environmental Data

Average total annual rainfall for the area of Lingshan landfill is 776 mm, and annual average temperature is 12°C. This area of China is categorized as “cold and dry” climate zone in the US EPA’s China Landfill Gas Model (v1.1, March, 2009).

3.3 Base Liner, and Cover

Base liner has been installed at Phase I and consists of 1.5 mm HDPE liner and woven/non-woven geotextile. Refuse is put in at 4 to 5 meters layer, covered by 0.5 mm HDPE cover. The HDPE cover is sewn and not heat fusion welded.

3.4 Waste Depth

The reported waste depth at the time of our visit ranged between 6 meter at the shallower end and 12 meter in the deepest section. The final waste depth in Phase I will be 15 meters. The waste depth for all three phases will reach a total of 41 meters, with approximately 35-meter height above ground surface.

3.5 Waste Placement/ Final Cover

Waste is brought to the site in both open and closed vehicles. The landfill operates 12 hours per day, 7 days a week. The bulldozers and backhoes are used to spread the waste. During the site visit on July 20, 2010, no compactor was observed at the landfill. Waste recycling/diversion activities were not observed during our site visit.

The final cover will be a 50 cm compacted soil layer.

3.6 Landfill Capacity/ Waste Inputs

Phase I started to accept waste in 2003; as of July 2010 phase I has 18 years of remaining active life. For the near future the daily waste acceptance rate is 400 tonnes per day (approximately 100,000 to 140,000 tonnes annually), and is expected to slowly increase to 500 tonnes per day.

Phase I covers an area of 134 meters (N-S) by 410 meters (E-W). The total area for phase I is approximately 55,000 square meters (5.5 hectare). As of July 2008, the site contained
approximately 690,000 tonnes of waste and is expected to eventually contain approximately 4.69 million tonnes when it reaches the proposed closure date of 2028.

Reported annual waste input to the landfill is shown in Table 1, and was provided by the landfill owner.

Table 1 – Waste Input 2003 - 2008

<table>
<thead>
<tr>
<th>Year</th>
<th>Total Tonnes</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003</td>
<td>85,000</td>
</tr>
<tr>
<td>2004</td>
<td>130,000</td>
</tr>
<tr>
<td>2005</td>
<td>132,000</td>
</tr>
<tr>
<td>2006</td>
<td>135,000</td>
</tr>
<tr>
<td>2007</td>
<td>138,000</td>
</tr>
<tr>
<td>2008</td>
<td>140,000</td>
</tr>
<tr>
<td>Total</td>
<td>760,000</td>
</tr>
</tbody>
</table>

Note: The total tonnes for year 2008 is estimated on 140,000 tonnes based on using the 70,000 tonnes for July through December 2008.

For the purpose of this study, the estimated waste input for the years 2009 through 2028 is assumed to be the same as that for 2008. The projected waste input from 2009 to the closure date is thus shown in Table 2.

Table 2 –Estimated Waste Input 2009 – 2028

<table>
<thead>
<tr>
<th>Year</th>
<th>Total Tonnes</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>140,000</td>
</tr>
<tr>
<td>2010</td>
<td>140,000</td>
</tr>
<tr>
<td>2011</td>
<td>140,000</td>
</tr>
<tr>
<td>2012</td>
<td>140,000</td>
</tr>
<tr>
<td>2013</td>
<td>140,000</td>
</tr>
<tr>
<td>2014</td>
<td>140,000</td>
</tr>
<tr>
<td>2015</td>
<td>140,000</td>
</tr>
<tr>
<td>2016</td>
<td>140,000</td>
</tr>
<tr>
<td>2017</td>
<td>140,000</td>
</tr>
<tr>
<td>2018</td>
<td>140,000</td>
</tr>
<tr>
<td>2019</td>
<td>140,000</td>
</tr>
<tr>
<td>2020</td>
<td>140,000</td>
</tr>
<tr>
<td>2021</td>
<td>140,000</td>
</tr>
<tr>
<td>2022</td>
<td>140,000</td>
</tr>
<tr>
<td>2023</td>
<td>140,000</td>
</tr>
<tr>
<td>2024</td>
<td>140,000</td>
</tr>
</tbody>
</table>
### Waste Composition

Based on the information provided in a questionnaire by the landfill manager, waste composition includes food waste, garden and park waste, wood, inert waste (dirt, rock, C&D), paper, textiles, plastics/ rubber/ tire, metals, glass and ceramics. Information regarding percent waste composition was not provided. Based on the questionnaire, the moisture content of the waste intake is about 30 percent. Exposed waste observed during our site visit consisted mainly of plastic, textile/ clothing, household waste, and minor amount of green waste. Based on the exposed refuse observed, the putrescible portion of the waste appeared less than 30 percent.

### GAS AND LEACHATE

#### Leachate

Leachate is formed by water entering the landfill, moving through the waste, and leaching contaminants from the waste. Contaminates in leachate, if not controlled, may contribute to groundwater contamination.

At Lingshan landfill, leachate is drained by gravity to leachate collection wells and pumped to the leachate treatment plant. The leachate treatment system uses aerobic/anaerobic and filtration methods including leachate recirculation using old waste and porcelain tubes as filtering material. Based on the information provided, the Chemical Oxygen Demand (COD) of leachate was reduced from 1,000 mg/L to 300 mg/L after treatment. After treatment, the leachate meets the National Discharge Level 2 Standard.

The onsite leachate plant has a design capacity of 70 m$^3$ per day for the Phase I area of the landfill. The current leachate recovery rate is 130 m$^3$ per day, with excess leachate being diverted to a local municipal wastewater treatment plant. Based on this information, the volume of leachate generated at the Phase I is similar to the annual precipitation over the Phase I area, indicating that waste acts as a sieve for rain water infiltration.

<table>
<thead>
<tr>
<th>Year</th>
<th>Total Tonnes</th>
</tr>
</thead>
<tbody>
<tr>
<td>2025</td>
<td>140,000</td>
</tr>
<tr>
<td>2026</td>
<td>140,000</td>
</tr>
<tr>
<td>2027</td>
<td>140,000</td>
</tr>
<tr>
<td>2028</td>
<td>140,000</td>
</tr>
<tr>
<td>Total Future</td>
<td>2,800,000 Tonnes</td>
</tr>
<tr>
<td>TOTAL</td>
<td>3,560,000 Tonnes</td>
</tr>
</tbody>
</table>
4.2 Landfill Gas

The landfill operator reported that 9 passive vents were constructed in the Phase I landfill. Vent wells were constructed of 150 mm diameter perforated HDPE pipes, in 1.5 m radius excavation filled with cobble, extending to the base of the landfill. Passive vents were initially installed in the Phase I area nominally 50 m apart. The spacing was later reduced to 25 m.

During our site visit on July 20, 2010, the gas composition from the vent wells was monitored using a CES-Landtec portable landfill gas analyzer. A certificate of calibration for the meter used is included in Appendix I. The measurements are summarized in Table 3 below.

Table 3 – Gas Measurements

<table>
<thead>
<tr>
<th>Lingshan Landfill – Phase I Passive Vent Wells</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weather Condition: Overcast and rainy</td>
</tr>
<tr>
<td>Ambient Pressure: 997 mb</td>
</tr>
<tr>
<td>Monitoring Personnel: Jason Leung</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Gas Vent 1(a)</th>
<th>Gas Vent 2(a)</th>
<th>Gas Vent 3(a)</th>
<th>Gas Vent 4(a)</th>
<th>Gas Vent 5(a)</th>
<th>Gas Vent 6(b)</th>
<th>Gas Vent 7(c)</th>
<th>Gas Vent 8</th>
<th>Gas Vent 9</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH4</td>
<td>3.6</td>
<td>0.4</td>
<td>0.1</td>
<td>2.3</td>
<td>0.9</td>
<td>13.4</td>
<td>8.7</td>
<td>NM</td>
<td>NM</td>
</tr>
<tr>
<td>CO2</td>
<td>2.9</td>
<td>0.6</td>
<td>0.1</td>
<td>1.6</td>
<td>1.0</td>
<td>9.3</td>
<td>7.6</td>
<td>NM</td>
<td>NM</td>
</tr>
<tr>
<td>O2</td>
<td>18.9</td>
<td>20.0</td>
<td>20.4</td>
<td>19.5</td>
<td>19.7</td>
<td>15.1</td>
<td>17.0</td>
<td>NM</td>
<td>NM</td>
</tr>
<tr>
<td>Balance gas</td>
<td>74.6</td>
<td>79.0</td>
<td>79.4</td>
<td>76.6</td>
<td>78.4</td>
<td>62.2</td>
<td>66.7</td>
<td>NM</td>
<td>NM</td>
</tr>
<tr>
<td>Ratio CH4/CO2</td>
<td>1.24</td>
<td>0.67</td>
<td>1.0</td>
<td>1.43</td>
<td>.9</td>
<td>1.44</td>
<td>1.14</td>
<td>---</td>
<td>---</td>
</tr>
</tbody>
</table>

Notes:
(a) - Surrounding area covered by HDPE membrane
(b) - Surrounding area covered by HDPE membrane less than 1 week
(c) - Vent on fresh waste; no HDPE membrane
NM – Not Measured; Vent well surrounded by wet mud

5. LANDFILL GAS MODELING

Methane gas is produced in landfills as a result of the anaerobic decomposition of organic matter (primary cellulose) according to the following general equation (Bushwell & Mueller, 1952):
\[ C_nH_aO_b + (n - \frac{a}{2} - \frac{b}{2})H_2O \rightarrow \left(\frac{n}{2} - \frac{a}{8} + \frac{b}{4}\right)CO_2 + \left(\frac{n}{2} + \frac{a}{8} - \frac{b}{4}\right)CH_4 \]

Although theorists have suggested many different models to describe the rate of decomposition, the most common mathematical sanitary landfill methane generation model in use today is a lumped parameter exponential decay model based on the first order decay equation:

**Equation 1** \[ Y_t = L_0 \times k \times e^{-kt} \]

Where;

- \(Y_t\) = Methane yield at time \(t\), in units of \(\frac{\text{CH}_4 \text{ Volume}}{\text{Mass} \times \text{Time}}\)
- \(L_0\) = Total potential yield in units of \(\frac{\text{CH}_4 \text{ Volume}}{\text{Mass}}\)
- \(t\) = Time at which the yield is calculated from time of waste deposition
- \(k\) = Rate constant is the approximate fraction of waste that decomposes in unit of \(\frac{\text{Time}}{\text{Time}}\)

The total methane production from a given mass of refuse during a given time period can then be determined using the equation:

**Equation 2** \[ P_t = Y_t \times M_t \]

where:

- \(P_t\) = Methane production in time \(t\), in units of \(\frac{\text{CH}_4 \text{ Volume}}{\text{Time}}\)
- \(M\) = Mass of refuse deposited during time \(t\)

Any increment of time may be used as a basis for the model for refuse placement in the landfill, however, it is seldom justified to use an increment smaller than one year. Therefore, all refuse for each year is assumed to be placed in the landfill on the last day of the year. In a lumped parameter model, all of a given year's refuse is assumed to be deposited at one time. The next year's refuse is deposited exactly one year from the previous year's, and so on from the first year of deposition to the last. The model does not use a lag time for the delay between refuse placement and initial methane production. Rather, the lump time of one year has an inherent average lag time of six months due to the average refuse age before methane generation is calculated by the model.
There are several approaches that can be used to model LFG generation. In this project, US EPA’s China Landfill Gas Model (v1.1, March, 2009) was utilized to estimate the methane and LFG collection rate. This model selects recommended values for k and Lo based on the site-specific information, like coal ash content in waste and landfill climate zone (Table 4).

Table 4 – Methane generation rate (k) and generation potential (Lo)

<table>
<thead>
<tr>
<th>Climate Zone</th>
<th>k (per year)</th>
<th>Lo (m³/Mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coal Ash Content &lt;30%</td>
<td>Coal Ash Content &gt;30%</td>
</tr>
<tr>
<td>Cold and Dry</td>
<td>0.04</td>
<td>70</td>
</tr>
<tr>
<td>Cold and Wet</td>
<td>0.11</td>
<td>56</td>
</tr>
<tr>
<td>Hot and Wet</td>
<td>0.18</td>
<td>56</td>
</tr>
</tbody>
</table>

The model also includes the effect of subsurface fire and some solid waste management practices, including compaction, shape of landfill, leachate flowing, depth of waste, liner/cover availability, and LFG system coverage percentage.

6. RESULTS OF LANDFILL GAS MODEL

Results of the U.S. EPA’s China Landfill Gas Model are given in the following graph (Figure 1).

According to the EPA Model, the Lingshan landfill is located in the “Cold and Dry” zone. In addition, based on the information provided, the landfill receives less than 30 percent coal ash. Therefore, using 0.04 1/yr. for k, and 70 m³ methane/Mg L₀, the Model estimates that the current LFG production is about 298 SCFM of landfill gas at 50% methane and that this emission rate will rise to a peak of approximately 841 SCFM in 2029, shortly after closure of the landfill in 2028.
Figure 1 – Landfill Gas Emissions

7. LFG COLLECTION EFFICIENCY

Collection efficiency is a measure of the ability of the gas collection system to capture generated LFG. It is a percentage value and can be applied to the LFG generation rate to estimate the amount of LFG that can be captured for flaring or beneficial use.

The gas collection system efficiency was estimated by the Model based on the our observation of the existing solid waste management practices, an assumed LFG system coverage percentage, and the information provided by the landfill owner. Based on this information, a collection efficiency of 64% was estimated at the Lingshan landfill. When this factor is applied to the Model, the current estimated LFG collection rate is 191 SCFM and maximum in 2029 is 538 SCFM. The estimated recovery rates are shown on Table 5.
**Table 5 – China Landfill Gas Model Results (@50% CH₄, 64% collection efficiency)**

<table>
<thead>
<tr>
<th>Year</th>
<th>Waste In-Place (000’s)</th>
<th>LFG Generation Rate (SCFM)</th>
<th>LFG Generation Rate (m³/hr)</th>
<th>LFG Recovery Rate (SCFM)</th>
<th>LFG Recovery Rate (m³/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>1,040</td>
<td>298</td>
<td>507</td>
<td>191</td>
<td>324</td>
</tr>
<tr>
<td>2011</td>
<td>1,180</td>
<td>338</td>
<td>575</td>
<td>216</td>
<td>368</td>
</tr>
<tr>
<td>2012</td>
<td>1,320</td>
<td>377</td>
<td>640</td>
<td>241</td>
<td>410</td>
</tr>
<tr>
<td>2013</td>
<td>1,460</td>
<td>414</td>
<td>703</td>
<td>265</td>
<td>450</td>
</tr>
<tr>
<td>2014</td>
<td>1,600</td>
<td>449</td>
<td>763</td>
<td>287</td>
<td>488</td>
</tr>
<tr>
<td>2015</td>
<td>1,740</td>
<td>483</td>
<td>821</td>
<td>309</td>
<td>525</td>
</tr>
<tr>
<td>2016</td>
<td>1,880</td>
<td>516</td>
<td>877</td>
<td>330</td>
<td>561</td>
</tr>
<tr>
<td>2017</td>
<td>2,020</td>
<td>547</td>
<td>930</td>
<td>350</td>
<td>595</td>
</tr>
<tr>
<td>2018</td>
<td>2,160</td>
<td>578</td>
<td>982</td>
<td>370</td>
<td>628</td>
</tr>
<tr>
<td>2019</td>
<td>2,300</td>
<td>607</td>
<td>1031</td>
<td>388</td>
<td>660</td>
</tr>
<tr>
<td>2020</td>
<td>2,440</td>
<td>635</td>
<td>1078</td>
<td>406</td>
<td>690</td>
</tr>
<tr>
<td>2021</td>
<td>2,580</td>
<td>661</td>
<td>1124</td>
<td>423</td>
<td>719</td>
</tr>
<tr>
<td>2022</td>
<td>2,720</td>
<td>687</td>
<td>1168</td>
<td>440</td>
<td>747</td>
</tr>
<tr>
<td>2023</td>
<td>2,860</td>
<td>712</td>
<td>1210</td>
<td>456</td>
<td>774</td>
</tr>
<tr>
<td>2024</td>
<td>3,000</td>
<td>736</td>
<td>1250</td>
<td>471</td>
<td>800</td>
</tr>
<tr>
<td>2025</td>
<td>3,140</td>
<td>759</td>
<td>1289</td>
<td>485</td>
<td>825</td>
</tr>
<tr>
<td>2026</td>
<td>3,280</td>
<td>781</td>
<td>1326</td>
<td>500</td>
<td>849</td>
</tr>
<tr>
<td>2027</td>
<td>3,420</td>
<td>802</td>
<td>1362</td>
<td>513</td>
<td>872</td>
</tr>
<tr>
<td>2028</td>
<td>3,560</td>
<td>822</td>
<td>1397</td>
<td>526</td>
<td>894</td>
</tr>
<tr>
<td>2029</td>
<td>3,560</td>
<td>841</td>
<td>1430</td>
<td>538</td>
<td>915</td>
</tr>
<tr>
<td>2030</td>
<td>3,560</td>
<td>808</td>
<td>1374</td>
<td>517</td>
<td>879</td>
</tr>
<tr>
<td>2031</td>
<td>3,560</td>
<td>777</td>
<td>1320</td>
<td>497</td>
<td>845</td>
</tr>
<tr>
<td>2032</td>
<td>3,560</td>
<td>746</td>
<td>1268</td>
<td>478</td>
<td>812</td>
</tr>
<tr>
<td>2033</td>
<td>3,560</td>
<td>717</td>
<td>1218</td>
<td>459</td>
<td>780</td>
</tr>
<tr>
<td>2034</td>
<td>3,560</td>
<td>689</td>
<td>1171</td>
<td>441</td>
<td>749</td>
</tr>
<tr>
<td>2035</td>
<td>3,560</td>
<td>662</td>
<td>1125</td>
<td>424</td>
<td>720</td>
</tr>
<tr>
<td>2036</td>
<td>3,560</td>
<td>636</td>
<td>1081</td>
<td>407</td>
<td>692</td>
</tr>
<tr>
<td>2037</td>
<td>3,560</td>
<td>611</td>
<td>1038</td>
<td>391</td>
<td>664</td>
</tr>
<tr>
<td>2038</td>
<td>3,560</td>
<td>587</td>
<td>997</td>
<td>376</td>
<td>638</td>
</tr>
<tr>
<td>2039</td>
<td>3,560</td>
<td>564</td>
<td>958</td>
<td>361</td>
<td>613</td>
</tr>
<tr>
<td>2040</td>
<td>3,560</td>
<td>542</td>
<td>921</td>
<td>347</td>
<td>589</td>
</tr>
</tbody>
</table>

### 8. AVAILABLE THERMAL ENERGY

Landfill methane has a calorific value of approximately 1012 Btu/cf (37,680 KJ/m³) higher heating value; however, because the landfill gas contains approximately 50% combustible and 50% non-combustible compound, the resultant thermal energy contained in landfill gas is 506 Btu/cf (18,840 KJ/m³). **Table 6** shows the estimated available thermal energy.
Table 6 – Estimated Landfill Gas Available Thermal Energy

<table>
<thead>
<tr>
<th>Year</th>
<th>Waste In-Place (000's)</th>
<th>LFG Recovery Rate (SCFM)</th>
<th>LFG Recovery Rate (m3/hr)</th>
<th>Thermal Energy MMBtu/hr</th>
<th>Thermal Energy MKJ/hr</th>
<th>Thermal Energy kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>1040</td>
<td>191</td>
<td>324</td>
<td>5.8</td>
<td>6.1</td>
<td>1,694</td>
</tr>
<tr>
<td>2011</td>
<td>1180</td>
<td>216</td>
<td>368</td>
<td>6.6</td>
<td>6.9</td>
<td>1,921</td>
</tr>
<tr>
<td>2012</td>
<td>1320</td>
<td>241</td>
<td>410</td>
<td>7.3</td>
<td>7.7</td>
<td>2,140</td>
</tr>
<tr>
<td>2013</td>
<td>1460</td>
<td>265</td>
<td>450</td>
<td>8.0</td>
<td>8.5</td>
<td>2,350</td>
</tr>
<tr>
<td>2014</td>
<td>1600</td>
<td>287</td>
<td>488</td>
<td>8.7</td>
<td>9.2</td>
<td>2,551</td>
</tr>
<tr>
<td>2015</td>
<td>1740</td>
<td>309</td>
<td>525</td>
<td>9.4</td>
<td>9.9</td>
<td>2,745</td>
</tr>
<tr>
<td>2016</td>
<td>1880</td>
<td>330</td>
<td>561</td>
<td>10.0</td>
<td>10.6</td>
<td>2,931</td>
</tr>
<tr>
<td>2017</td>
<td>2020</td>
<td>350</td>
<td>595</td>
<td>10.6</td>
<td>11.2</td>
<td>3,110</td>
</tr>
<tr>
<td>2018</td>
<td>2160</td>
<td>370</td>
<td>628</td>
<td>11.2</td>
<td>11.8</td>
<td>3,282</td>
</tr>
<tr>
<td>2019</td>
<td>2300</td>
<td>388</td>
<td>660</td>
<td>11.8</td>
<td>12.4</td>
<td>3,447</td>
</tr>
<tr>
<td>2020</td>
<td>2440</td>
<td>406</td>
<td>690</td>
<td>12.3</td>
<td>13.0</td>
<td>3,605</td>
</tr>
<tr>
<td>2021</td>
<td>2580</td>
<td>423</td>
<td>719</td>
<td>12.9</td>
<td>13.6</td>
<td>3,758</td>
</tr>
<tr>
<td>2022</td>
<td>2720</td>
<td>440</td>
<td>747</td>
<td>13.4</td>
<td>14.1</td>
<td>3,904</td>
</tr>
<tr>
<td>2023</td>
<td>2860</td>
<td>456</td>
<td>774</td>
<td>13.8</td>
<td>14.6</td>
<td>4,045</td>
</tr>
<tr>
<td>2024</td>
<td>3000</td>
<td>471</td>
<td>800</td>
<td>14.3</td>
<td>15.1</td>
<td>4,180</td>
</tr>
<tr>
<td>2025</td>
<td>3140</td>
<td>485</td>
<td>825</td>
<td>14.7</td>
<td>15.5</td>
<td>4,310</td>
</tr>
<tr>
<td>2026</td>
<td>3280</td>
<td>500</td>
<td>849</td>
<td>15.2</td>
<td>16.0</td>
<td>4,434</td>
</tr>
<tr>
<td>2027</td>
<td>3420</td>
<td>513</td>
<td>872</td>
<td>15.6</td>
<td>16.4</td>
<td>4,554</td>
</tr>
<tr>
<td>2028</td>
<td>3560</td>
<td>526</td>
<td>894</td>
<td>16.0</td>
<td>16.8</td>
<td>4,670</td>
</tr>
<tr>
<td>2029</td>
<td>3560</td>
<td>538</td>
<td>915</td>
<td>16.3</td>
<td>17.2</td>
<td>4,780</td>
</tr>
<tr>
<td>2030</td>
<td>3560</td>
<td>517</td>
<td>879</td>
<td>15.7</td>
<td>16.6</td>
<td>4,593</td>
</tr>
<tr>
<td>2031</td>
<td>3560</td>
<td>497</td>
<td>845</td>
<td>15.1</td>
<td>15.9</td>
<td>4,413</td>
</tr>
<tr>
<td>2032</td>
<td>3560</td>
<td>478</td>
<td>812</td>
<td>14.5</td>
<td>15.3</td>
<td>4,240</td>
</tr>
<tr>
<td>2033</td>
<td>3560</td>
<td>459</td>
<td>780</td>
<td>13.9</td>
<td>14.7</td>
<td>4,073</td>
</tr>
<tr>
<td>2034</td>
<td>3560</td>
<td>441</td>
<td>749</td>
<td>13.4</td>
<td>14.1</td>
<td>3,914</td>
</tr>
<tr>
<td>2035</td>
<td>3560</td>
<td>424</td>
<td>720</td>
<td>12.9</td>
<td>13.6</td>
<td>3,760</td>
</tr>
<tr>
<td>2036</td>
<td>3560</td>
<td>407</td>
<td>692</td>
<td>12.4</td>
<td>13.0</td>
<td>3,613</td>
</tr>
<tr>
<td>2037</td>
<td>3560</td>
<td>391</td>
<td>664</td>
<td>11.9</td>
<td>12.5</td>
<td>3,471</td>
</tr>
<tr>
<td>2038</td>
<td>3560</td>
<td>376</td>
<td>638</td>
<td>11.4</td>
<td>12.0</td>
<td>3,335</td>
</tr>
<tr>
<td>2039</td>
<td>3560</td>
<td>361</td>
<td>613</td>
<td>11.0</td>
<td>11.6</td>
<td>3,204</td>
</tr>
<tr>
<td>2040</td>
<td>3560</td>
<td>347</td>
<td>589</td>
<td>10.5</td>
<td>11.1</td>
<td>3,079</td>
</tr>
</tbody>
</table>

In general, there are three alternatives for LFG utilization; they are 1) Power production or cogeneration, 2) Direct medium-BTU gas use, and 3) Sale of upgraded pipeline quality (high-BTU) gas.

The quickest use of LFG is usually power generation. Power generation by LFG is a mature industry with hundreds of facilities operating throughout the world. Low emission lean burning
engines can be used for the power production project. Engine manufacturers can package an engine with the generator and all necessary controls and switchgear making this a relatively simple installation. An alternative approach is to use small Chinese manufactured engine to produce power. The advantage of this approach is the ability to provide parts and service the equipment locally.

The second alternative for LFG utilization is direct burning of LFG. Most of the medium-BTU LFG can be burned in a packaged boiler to provide steam to a process. This kind of system has high on-stream reliability and typically the highest use of the heat provided by LFG.

The third project option is to upgrade the LFG to a high-BTU product for injection into a natural gas pipeline. Either membrane, pressure swing adsorption (PSA), or other gas treatment process can be utilized to remove carbon dioxide, and other impurities. Specialized processes can also be used for nitrogen removal. Because of the relatively high capital cost of this option, it may be cost-effective only for those landfills with substantial recoverable gas.

9. EMISSION REDUCTION ESTIMATION

To assess the feasibility for trading of emission reductions, the calculation of available emission reductions was conducted. The following equation was utilized to calculate the annual available emission reduction for Lingshan landfill.

\[ M_{CO_{2eq}} = (1 - AF) \times \frac{0.016 \times Q_{CH_4}}{22.4} \times 21 \]

where,

- \( M_{CO_{2eq}} \) = Total annual available emission reduction in Tonnes of Carbon Dioxide Equivalent (tCO₂e)
- AF = Adjustment Factor (0% in this case)
- 0.016 = Molecular weight of methane (tonne/kmol)
- \( Q_{CH_4} \) = Total methane generated annually
- 22.4 = Molecular volume at 0°C (m³/kmol)
- 21 = Global Warming Potential (GWP) of methane

Actual emission reduction is dependent on the recovered methane. If the methane is flared, the methane is reacting to form CO₂. Because the methane contained in LFG can be classified as biomass under the current methodologies, the CO₂ emissions resulting from the flaring is considered to be a product of the normal carbon cycle and do not have to be accounted for.

If the methane is used for the production of electricity, it may result in additional emission reductions. It is possible that the project will displace the power from other existing power plants, or that the project will make an investment in a new power plant unnecessary. To calculate the emission reduction available in each year, the following equation can be used.
\[ M_{\text{CO}_2\text{eq.}} = EF_{\text{grid}} \times MWh_{\text{exported}} \]

where,
\[ M_{\text{CO}_2\text{eq.}} = \text{Total annual available emission reduction in Tonnes of Carbon Dioxide Equivalent (tCO}_2\text{e)} \]
\[ EF_{\text{grid}} = \text{Grid emission factor (tCO}_2\text{e/MWh, Table 5- China’s Grid Baseline Emission Factors for Candidate landfills)} \]
\[ MWh_{\text{exported}} = \text{Total number of mega-watt hours exported to the grid.} \]

Normally the cost of implementation of Clean Development Mechanism (CDM) projects will have risks and costs associated with it. Therefore, the feasibility study shall include the evaluation of the potential costs, benefits, and risks of using a CDM mechanism. If this approach is used, a partial list of funding sources could come from programs like UK Climate Change Challenge Fund, SWISS AIJ Pilot Program, Netherlands CDM Program, Oregon Climate Trust, … etc.

Assuming that all of the methane is used for energy generation (including direct use) and/or flaring, the possible number of emission reductions generated is shown in Table 7. Emission reductions produced by the generation of electricity are additional to flaring activities. The estimates shown in Table 7 are based on the assumption that an enclosed flare is used to ensure a high combustion efficiency (>99%), and that the efficiency of the engine / generator is approximately 38% gross minus parasitic losses or about 35% net.

<table>
<thead>
<tr>
<th>Year</th>
<th>CO2 Equivalent Tonnes from Flaring Activities</th>
<th>Additional CO2 Equivalent Tonnes from Electricity Generation*</th>
<th>Total CO2 Equivalent Tonnes</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>21,305</td>
<td>4,574</td>
<td>25,879</td>
</tr>
<tr>
<td>2011</td>
<td>24,163</td>
<td>5,188</td>
<td>29,351</td>
</tr>
<tr>
<td>2012</td>
<td>26,910</td>
<td>5,777</td>
<td>32,687</td>
</tr>
<tr>
<td>2013</td>
<td>29,549</td>
<td>6,344</td>
<td>35,893</td>
</tr>
<tr>
<td>2014</td>
<td>32,084</td>
<td>6,888</td>
<td>38,972</td>
</tr>
<tr>
<td>2015</td>
<td>34,520</td>
<td>7,411</td>
<td>41,931</td>
</tr>
<tr>
<td>2016</td>
<td>36,861</td>
<td>7,914</td>
<td>44,774</td>
</tr>
<tr>
<td>2017</td>
<td>39,110</td>
<td>8,396</td>
<td>47,506</td>
</tr>
<tr>
<td>2018</td>
<td>41,270</td>
<td>8,860</td>
<td>50,130</td>
</tr>
<tr>
<td>2019</td>
<td>43,346</td>
<td>9,306</td>
<td>52,652</td>
</tr>
<tr>
<td>2020</td>
<td>45,340</td>
<td>9,734</td>
<td>55,075</td>
</tr>
<tr>
<td>Year</td>
<td>CO2 Equivalent Tonnes from Flaring Activities</td>
<td>Additional CO2 Equivalent Tonnes from Electricity Generation*</td>
<td>Total CO2 Equivalent Tonnes</td>
</tr>
<tr>
<td>------</td>
<td>---------------------------------------------</td>
<td>----------------------------------------------------------</td>
<td>-----------------------------</td>
</tr>
<tr>
<td>2021</td>
<td>47,257</td>
<td>10,145</td>
<td>57,402</td>
</tr>
<tr>
<td>2022</td>
<td>49,098</td>
<td>10,541</td>
<td>59,639</td>
</tr>
<tr>
<td>2023</td>
<td>50,867</td>
<td>10,920</td>
<td>61,787</td>
</tr>
<tr>
<td>2024</td>
<td>52,566</td>
<td>11,285</td>
<td>63,852</td>
</tr>
<tr>
<td>2025</td>
<td>54,199</td>
<td>11,636</td>
<td>65,835</td>
</tr>
<tr>
<td>2026</td>
<td>55,768</td>
<td>11,973</td>
<td>67,741</td>
</tr>
<tr>
<td>2027</td>
<td>57,276</td>
<td>12,296</td>
<td>69,572</td>
</tr>
<tr>
<td>2028</td>
<td>58,724</td>
<td>12,607</td>
<td>71,331</td>
</tr>
<tr>
<td>2029</td>
<td>60,115</td>
<td>12,906</td>
<td>73,021</td>
</tr>
<tr>
<td>2030</td>
<td>57,758</td>
<td>12,400</td>
<td>70,158</td>
</tr>
<tr>
<td>2031</td>
<td>55,493</td>
<td>11,914</td>
<td>67,407</td>
</tr>
<tr>
<td>2032</td>
<td>53,317</td>
<td>11,447</td>
<td>64,764</td>
</tr>
<tr>
<td>2033</td>
<td>51,227</td>
<td>10,998</td>
<td>62,225</td>
</tr>
<tr>
<td>2034</td>
<td>49,218</td>
<td>10,567</td>
<td>59,785</td>
</tr>
<tr>
<td>2035</td>
<td>47,288</td>
<td>10,152</td>
<td>57,441</td>
</tr>
<tr>
<td>2036</td>
<td>45,434</td>
<td>9,754</td>
<td>55,188</td>
</tr>
<tr>
<td>2037</td>
<td>43,653</td>
<td>9,372</td>
<td>53,024</td>
</tr>
<tr>
<td>2038</td>
<td>41,941</td>
<td>9,004</td>
<td>50,945</td>
</tr>
<tr>
<td>2039</td>
<td>40,296</td>
<td>8,651</td>
<td>48,948</td>
</tr>
<tr>
<td>2040</td>
<td>38,716</td>
<td>8,312</td>
<td>47,028</td>
</tr>
</tbody>
</table>

*Provided that the installed capacity of electricity generating equipment exceeds gas availability at all times.

It should be noted that the quantity of emission reductions would generally fall below the available estimates shown in Table 7. It will be affected by such factors as downtime of the LFG collection, flaring and utilization system, efficiency of the electricity generator, destruction efficiency of the flare and other equipment (such as electrical generator), and parasitic loss efficiency.

10. OUTLINE SPECIFICATION OF A GAS EXTRACTION SYSTEM

To collect the landfill gas from the Lingshan landfill, a gas collection system must be installed. The following general description outlines the equipment and operations required for this purpose.

The main components of landfill gas collection systems are gas extraction wells, lateral and header pipes, vacuum / pressure, blower, flare, (or other kind of combustion device) condensate water handling system, and controls. The detail functions of the components are described as follows.
Vertical wells can be installed during landfill filling, like in Phase I. Due to the high cost of drilling (relative to the amount of landfill gas available), the option to use horizontal gas collectors is considered. Horizontal gas collection pipes, which typically consist of plastic pipe sections, could be installed directly on top of waste or in excavated trenches. Gas extraction wells should be equipped with a hand flow control valve and monitoring port to adjust the LFG extraction rate and measure gas quality. A key characteristic of all LFG extraction wells is the need to keep the gas collection sufficiently deep so they do not readily pull air into the refuse.

The LFG collection system should use lateral pipes for connecting wells to headers. The laterals and headers should be sized to accommodate present and future gas production. Because the landfill is in a cold part of China, the gas system needs to be able to accommodate freezing weather without forming ice in the pipe. This is best accomplished by burying the pipe to keep ice from forming.

To help facilitate well construction and gas collection, it is recommended that smaller phases be selected that can be filled to the ultimate design height before collecting LFG. Even in cold climates it is common for well heads to extend above the landfill before going back down into a buried lateral. This is done to help facilitate operation and maintenance of the gas system.

The LFG system can use HDPE or other local suitable material for LFG piping. To the extent possible to reduce pipe maintenance, the main LFG collection header should be installed outside refuse. If installed on native soil, the headers may be installed in trenches with a minimum 0.25% slope. If on refuse, buried headers should have at least 2% - 3% slope. Above ground headers should use available slope provided it is greater than 1%. All low points require a condensate water drain to remove water from the gas pipe. Caution will need to be exercised to make sure water in the gas pipe doesn’t freeze. The header system should be sectioned with isolation valves to help facilitate maintenance. Monitoring ports should be installed adjacent to isolation valve.

Landfill gas is pulled to a flare station using vacuum produced by a blower. Gas discharge from a blower will go to either a flare or an energy user. Blowers should have sufficient vacuum capacity to provide nominally 10” WC vacuum at the flow control on each well. Two different types of flare stacks exist for thermal oxidation of landfill gas: Enclosed flare, in which the landfill gas is combusted in a temperature controlled chamber; and, "elevated" or "candle stick flares” which burns gas in an open flame and requires considerably lower capital cost. For landfills with low predicted gas availability, it may be preferable to use lower cost flare equipment, particularly in cases where most of the landfill gas will be delivered to other utilization equipment.

Condensate water collected in the landfill site should be handled as leachate.
11. FINANCE MODEL

A preliminary financial assessment of alternative LFG energy projects at the Lingshan landfill has been performed using the Landfill Gas Energy Cost Model (LFGcost, Version 2.0, EPA 2009). This software tool evaluates the economical feasibility based on typical project designs and for typical landfill situation. The report provided a crude breakdown of the capital costs of LFG project components.

Several options exist to utilize landfill gas if and when sufficient gas is available. These include both industrial users and power generation. Because of the low landfill gas generation rate, upgrading the methane to high BTU gas is not considered practical at this time and is not considered in this evaluation.

In addition to utilization options, there are also benefits of collecting landfill gas and burning the methane for the greenhouse gas emission reduction credits that are generated. The sale of these credits will provide a second revenue source. Financial evaluations were run using emission reduction credits of $0, $4, and $8/MTCO₂e.

11.1 Medium BTU Fuel

Even though there is no nearby medium BTU fuel user observed during this site visit, this option is included for potential use in the future should an end user move to the landfill vicinity, and or the landfill owner opts to use the fuel for onsite utility. LFGcost was used to estimate the Direct Use Project Economics (Appendix II). The estimated cost is based on a potential end user within 10 miles radius of the landfill. A common set of assumptions is used in all financial evaluations. Assumptions are shown on print outs from the model shown in Appendix II. According to the model, this type of project is only viable with greenhouse gas emission reduction credits greater than $8/MTCO₂e. This model assumes LFG use is continuous. The model assumes that the LFG collection and flare systems will be part of the project costs. Because the project will be built in China, both material and labor costs for part of the systems may be less than in the United States of America, hence, it may be possible to reduce some of the capital costs, thus improving the economics.

11.2 Power Generation

A second utilization option is to generate power. Based on the financial model calculations, a power generation project will have the best potential to have an acceptable internal rate of return. Because the landfill is still in its Phase I, engine generators will need to be installed in small increments to match the methane gas collection rate. The National Renewable Energy Law implemented in 2006 helps facilitate renewable power generation in China. An amendment passed in December 2009 requires electricity utilities to buy all the power produced by renewable energy generators. Another possibility is onsite use of power.
LFGcost was used to estimate the Small Power Production Project Economics (Appendix III). According to the output, this project is only viable with greenhouse gas emission reduction credits greater than $4/MTCO$_{2}$e to pay for part of the capital cost. The model assumes that the LFG collection and flare systems will be part of the project costs. Because the project will be built in China, it may be possible to reduce some of the capital costs, thus improving the economics.

11.3 Small Engines/Power Production

Small engines in China have the advantage of being able to utilize locally manufactured equipment and provide all service and parts using Chinese companies. This option also allows small increment sizes as a project is expanded, thus potentially using more LFG for power production. A common disadvantage of small engines is the reduced efficiency when compared to large bore internal combustion engines.

LFGcost was used to estimate the small engine project economics (Appendix IV). The IRR for this approach is poorest and will only be viable with greenhouse gas emission reduction credits greater than $4/MTCO$_{2}$e.

11.4 Financial Model Summary

A summary of the LFGcost results is presented in Table 8. Figure 2 has been prepared to show the internal rate of return (IRR) for each of the different project types.

### Table 8 – Summary of LFGcost Results

<table>
<thead>
<tr>
<th>Energy Project Type</th>
<th>Capital Cost</th>
<th>1st yr O&amp;M Cost</th>
<th>Emission Reductions Price ($/tCO2e)</th>
<th>IRR</th>
<th>4</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct Use</td>
<td>$4,795,726</td>
<td>$128,753</td>
<td>0</td>
<td>-17%</td>
<td>-6%</td>
<td>2%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>NPV</td>
<td>-$3,203,058</td>
<td>-$2,115,712</td>
<td>-$1,173,592</td>
</tr>
<tr>
<td>Standard Reciprocating Engine-Generator</td>
<td>$1,891,285</td>
<td>$181,928</td>
<td>IRR</td>
<td>-8%</td>
<td>10%</td>
<td>23%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>NPV</td>
<td>-$901,955</td>
<td>-$4,067</td>
<td>$738,754</td>
</tr>
<tr>
<td>Small Engine</td>
<td>$1,511,062</td>
<td>$151,056</td>
<td>IRR</td>
<td>-36%</td>
<td>5%</td>
<td>21%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>NPV</td>
<td>-$1,213,007</td>
<td>-$222,683</td>
<td>$518,401</td>
</tr>
</tbody>
</table>
12. CONCLUSIONS

The analysis documented in this assessment report indicates that the Lingshan landfill produces a moderate and steadily increasing amount of LFG. However, Project development does not appear to be economical at this time for multiple reasons. First and foremost, there is no nearby user for direct fuel use, which is the most economical solution of this project, unless the landfill owner opts to use the fuel for onsite electricity use. Second, based on the result provided by LFGcost program, greenhouse gas emission reduction credits will be required for a project to work. With the current world wide financial situation, the market for greenhouse gas emission reduction credits is down, but this is not expected to last. In the mean time, the proper solid waste management practices shall be implemented in preparation for project development.
APPENDIX I
Certificate of GA 2000 Calibration
GAS ANALYZER CALIBRATION REPORT

Calibration Date: 16-Jul-10

DETAILS OF EQUIPMENT TO BE CALIBRATED

Equipment: CES-Landtec Portable Landfill Gas Analyzer
Model: GA 2000
Serial Number: GA11224
Measurement
CH₄: 0% - 100% v/v
CO₂: 0% - 60% v/v
O₂: 0% - 21% v/v

Range:
CH₄: 0% - 100% v/v
CO₂: 0% - 60% v/v
O₂: 0% - 21% v/v

Procedure: Check against calibration media on known concentrations.
Acceptance: If difference is less than tolerance, adjustment is not necessary.
Otherwise, the equipment is required to be adjusted to the specified gas concentrations and recalibrate.

Tolerance (F.S. - Full Scale)
<table>
<thead>
<tr>
<th></th>
<th>0 - 5% vol.</th>
<th>5 - 15% vol.</th>
<th>15% - F.S.</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH₄</td>
<td>±0.3%</td>
<td>±1%</td>
<td>±3%(100%)</td>
</tr>
<tr>
<td>CO₂</td>
<td>±0.3%</td>
<td>±1%</td>
<td>±3%(60%)</td>
</tr>
<tr>
<td>O₂</td>
<td>±1%</td>
<td>±1%</td>
<td>±3%(21%)</td>
</tr>
</tbody>
</table>

Certificate No.: T08/03950
Cylinder No.: P6176
Composition:

<table>
<thead>
<tr>
<th>Composition</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>N₂</td>
<td>14.8%</td>
</tr>
<tr>
<td>CO₂</td>
<td>35.7%</td>
</tr>
<tr>
<td>CH₄</td>
<td>49.5%</td>
</tr>
<tr>
<td>O₂</td>
<td>0.0%</td>
</tr>
</tbody>
</table>

Composition:

<table>
<thead>
<tr>
<th>Composition</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>N₂</td>
<td>14.8%</td>
</tr>
<tr>
<td>CO₂</td>
<td>35.7%</td>
</tr>
<tr>
<td>CH₄</td>
<td>49.5%</td>
</tr>
<tr>
<td>O₂</td>
<td>0.0%</td>
</tr>
</tbody>
</table>

CALIBRATION RESULT(S)

<table>
<thead>
<tr>
<th>Calibration on Standard Gas</th>
<th>Calibration on Ambient Air</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Air</td>
</tr>
<tr>
<td>CH₄</td>
<td>49.5%</td>
</tr>
<tr>
<td>CO₂</td>
<td>35.7%</td>
</tr>
<tr>
<td>O₂</td>
<td>0.0%</td>
</tr>
<tr>
<td>Balance gas</td>
<td>14.8%</td>
</tr>
</tbody>
</table>

Conclusion: Adjustment of GA2000 not necessary

Reported by: Jason Leung

Checked by: Louis Chan

Form Revised: March 2009
APPENDIX II
Direct Use
Project Economics
U.S. EPA Landfill Methane Outreach Program

Landfill Gas Energy Cost Model
LFGcost, Version 2.0
Summary Report

Landfill Name or Identifier: LINGSHAN LANDFILL, JI MO CITY, SHANDONG PROVINCE

LFGE Project Type: Direct Use

Date: Friday, February 04, 2011

Disclaimer:
LFGcost is a landfill gas energy project cost estimating tool developed for EPA's LMOP. LFGcost estimates landfill gas generation rates using a first-order decay equation. This equation is used to estimate generation potential but can not be considered an absolute predictor of the rate of landfill gas generation. Variations in the rate and types of incoming waste, site operating conditions, and moisture and temperature conditions may provide substantial variations in the actual rates of generation.

The costs that are estimated by LFGcost are based on typical project designs and for typical landfill situations. The model attempts to include all equipment, site work, permits, operating activities, and maintenance that would normally be required for constructing and operating a typical project. However, individual landfills may require unique design modifications which would add to the cost estimated by LFGcost.

Analyses performed using LFGcost are considered preliminary and should be used for guidance only. A detailed final feasibility assessment should be conducted by qualified landfill gas professionals prior to preparing a system design, initiating construction, purchasing materials, or entering into agreements to provide or purchase energy from a landfill gas project.

Summary Results
Project Start Year: 2012
Project End Year: 2026
Project Type: Direct Use

Financial Results:
Net Present Value: ($3,203,058) (at year of construction)
Internal Rate of Return: -17%
Net Present Value Payback (yrs): None (years after operation begins)
Installed Capital Costs:
Gas Collection and Flare: $540,742
Skid-mounted Filter, Compressor, and Dehydration Unit: $3,399,993
Pipeline to convey gas to project site: $4,795,726
Total Capital Costs: $128,753 (for initial year of operation)

These financial results include the costs associated with the gas collection and flaring system.
Environmental Benefits

Benefits from Collecting and Destroying Methane (during the life of the project):

Lifetime

<table>
<thead>
<tr>
<th>(million ft^3 methane):</th>
<th>1,533</th>
</tr>
</thead>
<tbody>
<tr>
<td>(MMTCO2E):</td>
<td>6.18E-01</td>
</tr>
</tbody>
</table>

Average Annual

<table>
<thead>
<tr>
<th>(million ft^3 methane/yr):</th>
<th>102</th>
</tr>
</thead>
<tbody>
<tr>
<td>(MMTCO2E/yr):</td>
<td>4.12E-02</td>
</tr>
</tbody>
</table>

Benefits from Avoided Direct Use of Fossil Fuels (during the life of the project):

<table>
<thead>
<tr>
<th>Lifetime (MMTCO2E):</th>
<th>4.60E-02</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Annual (MMTCO2E/yr):</td>
<td>3.06E-03</td>
</tr>
</tbody>
</table>

Landfill Characteristics

| Open Year: | 2003 |
| Closure Year: | 2028 |
| Waste-In-Place at Closure (tons): | 3,560,000 |
| Average Waste Acceptance (tons/yr): | 142,400 |
| Average Depth of Landfill Waste (ft): | 45 |
| Area of LFG Wellfield to Supply Project (acres): | 17 |

Landfill Gas Generation, Collection, and Utilization

Modeling Parameters for First-Order Decay Equation:

| Methane Generation Rate, k (1/yr): | 0.040 |
| Methane Generation Capacity, L_o (ft^3/ton): | 2,473 |
| Methane Content of LFG: | 50% |

Generated During Project Lifetime (ft^3/min):

| Minimum: | 384 |
| Annual Average: | 607 |
| Maximum: | 796 |

Collected During Project Lifetime (ft^3/min):

| Minimum: | 246 |
| Annual Average: | 389 |
| Maximum: | 509 |

Project Size: Minimum

Design Flow Rate for Project (ft^3/min): 246

Utilized by Project (ft^3/min):

| Annual Average: | 221 |

LFG Collection Efficiency: 64%

Financial Assumptions

| Loan Lifetime (years): | 10 |
| Interest Rate: | 8.0% |
| General Inflation Rate: | 2.5% (applied to O&M costs) |
| Equipment Inflation Rate: | 1.0% |
| Marginal Tax Rate: | 35.0% |
| Discount Rate: | 10.0% |
| Down Payment: | 20.0% |
| Collection and Flaring Costs: | Included |
**Direct Use Production and Sales Summary**

- **Pipeline Length From Landfill to End User (mi):** 10.0
- **LFG Average Utilization (million Btu/yr):** 58,806 *(during the life of the project)*
- **Initial Year LFG Price ($/million Btu):** 5
- **Price to Achieve Financial Goals ($/million Btu):** 5 *(determined by Financial Goals Calculator results)*

**Landfill Gas Generation, Collection, and Utilization Curve**

![Gas Generation, Collection, and Utilization Curve]

- **Gas Generation**
- **Gas Collection**
- **Gas Utilization**

---

REPORT - 3
U.S. EPA Landfill Methane Outreach Program

Landfill Gas Energy Cost Model
LFGcost, Version 2.0

Summary Report

Landfill Name or Identifier: LINGSHAN LANDFILL, JI MO CITY, SHANDONG PROVINCE

LFGE Project Type: Direct Use

Date: Friday, February 04, 2011

Disclaimer:
LFGcost is a landfill gas energy project cost estimating tool developed for EPA's LMOP. LFGcost estimates landfill gas generation rates using a first-order decay equation. This equation is used to estimate generation potential but cannot be considered an absolute predictor of the rate of landfill gas generation. Variations in the rate and types of incoming waste, site operating conditions, and moisture and temperature conditions may provide substantial variations in the actual rates of generation.

The costs that are estimated by LFGcost are based on typical project designs and for typical landfill situations. The model attempts to include all equipment, site work, permits, operating activities, and maintenance that would normally be required for constructing and operating a typical project. However, individual landfills may require unique design modifications which would add to the cost estimated by LFGcost.

Analyses performed using LFGcost are considered preliminary and should be used for guidance only. A detailed final feasibility assessment should be conducted by qualified landfill gas professionals prior to preparing a system design, initiating construction, purchasing materials, or entering into agreements to provide or purchase energy from a landfill gas project.

Summary Results
Project Start Year: 2012
Project End Year: 2026
Project Type: Direct Use

Financial Results:
Net Present Value: ($2,115,712) (at year of construction)
Internal Rate of Return: -6%
Net Present Value Payback (yrs): None (years after operation begins)
Installed Capital Costs:
Gas Collection and Flare: $540,742
Skid-mounted Filter, Compressor, and Dehydration Unit: $854,992
Pipeline to convey gas to project site: $3,399,993
Total Capital Costs: $4,795,726

O&M Costs: $128,753 (for initial year of operation)

These financial results include the costs associated with the gas collection and flaring system.

REPORT - 1
Environmental Benefits

Benefits from Collecting and Destroying Methane (during the life of the project):

Lifetime
- Methane (million ft³): 1,533
- MMTCO₂E: 6.18E-01

Average Annual
- Methane (million ft³/yr): 102
- MMTCO₂E/yr: 4.12E-02

Benefits from Avoided Direct Use of Fossil Fuels (during the life of the project):

Lifetime (MMTCO₂E): 4.60E-02
Average Annual (MMTCO₂E/yr): 3.06E-03

Landfill Characteristics

Open Year: 2003
Closure Year: 2028
Waste-In-Place at Closure (tons): 3,560,000
Average Waste Acceptance (tons/yr): 142,400
Average Depth of Landfill Waste (ft): 45
Area of LFG Wellfield to Supply Project (acres): 17

Landfill Gas Generation, Collection, and Utilization

Modeling Parameters for First-Order Decay Equation:
- Methane Generation Rate, k (1/yr): 0.040
- Methane Generation Capacity, L₀ (ft³/ton): 2,473
- Methane Content of LFG: 50%

Generated During Project Lifetime (ft³/min):
- Minimum: 384
- Annual Average: 607
- Maximum: 796

Collected During Project Lifetime (ft³/min):
- Minimum: 246
- Annual Average: 389
- Maximum: 509

Project Size:
- Minimum: 246
- Annual Average: 221

LFG Collection Efficiency: 64%

Financial Assumptions

Loan Lifetime (years): 10
Interest Rate: 8.0%

General Inflation Rate: 2.5% (applied to O&M costs)
Equipment Inflation Rate: 1.0%
Marginal Tax Rate: 35.0%
Discount Rate: 10.0%
Down Payment: 20.0%
Collection and Flaring Costs: Included
**Direct Use Production and Sales Summary**

- **Pipeline Length From Landfill to End User (mi):** 10.0
- **LFG Average Utilization (million Btu/yr):** 58,806 (during the life of the project)
- **Initial Year LFG Price ($/million Btu):** 5
- **Price to Achieve Financial Goals ($/million Btu):** 5 (determined by Financial Goals Calculator results)

---

**Landfill Gas Generation, Collection, and Utilization Curve**

[Graph showing the relationship between year and average annual landfill gas flow rate in ft³/min.]
**U.S. EPA Landfill Methane Outreach Program**

**Landfill Gas Energy Cost Model**

**LFGcost, Version 2.0**

**Summary Report**

Landfill Name or Identifier: LINGSHAN LANDFILL, JI MO CITY, SHANDONG PROVINCE

LFGE Project Type: Direct Use

Date: Friday, February 04, 2011

Disclaimer:

LFGcost is a landfill gas energy project cost estimating tool developed for EPA's LMOP. LFGcost estimates landfill gas generation rates using a first-order decay equation. This equation is used to estimate generation potential but can not be considered an absolute predictor of the rate of landfill gas generation. Variations in the rate and types of incoming waste, site operating conditions, and moisture and temperature conditions may provide substantial variations in the actual rates of generation.

The costs that are estimated by LFGcost are based on typical project designs and for typical landfill situations. The model attempts to include all equipment, site work, permits, operating activities, and maintenance that would normally be required for constructing and operating a typical project. However, individual landfills may require unique design modifications which would add to the cost estimated by LFGcost.

Analyses performed using LFGcost are considered preliminary and should be used for guidance only. A detailed final feasibility assessment should be conducted by qualified landfill gas professionals prior to preparing a system design, initiating construction, purchasing materials, or entering into agreements to provide or purchase energy from a landfill gas project.

**Summary Results**

<table>
<thead>
<tr>
<th>Project Start Year:</th>
<th>2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project End Year:</td>
<td>2026</td>
</tr>
<tr>
<td>Project Type:</td>
<td>Direct Use</td>
</tr>
</tbody>
</table>

**Financial Results:**

<table>
<thead>
<tr>
<th>Net Present Value:</th>
<th>($1,173,592) (at year of construction)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal Rate of Return</td>
<td>2%</td>
</tr>
<tr>
<td>Net Present Value Payback (yrs):</td>
<td>None (years after operation begins)</td>
</tr>
<tr>
<td>Installed Capital Costs:</td>
<td></td>
</tr>
<tr>
<td>Gas Collection and Flare:</td>
<td>$540,740</td>
</tr>
<tr>
<td>Skid-mounted Filter, Compressor, and Dehydration Unit:</td>
<td>$854,992</td>
</tr>
<tr>
<td>Pipeline to convey gas to project site:</td>
<td>$3,399,993</td>
</tr>
<tr>
<td>Total Capital Costs:</td>
<td>$4,795,726</td>
</tr>
<tr>
<td>O&amp;M Costs:</td>
<td>$128,753 (for initial year of operation)</td>
</tr>
</tbody>
</table>

These financial results include the costs associated with the gas collection and flaring system.
Environmental Benefits

Benefits from Collecting and Destroying Methane (during the life of the project):

Lifetime

(million ft³ methane): 1,533
(MMTCO₂E): 6.18E-01

Average Annual

(million ft³ methane/yr): 102
(MMTCO₂E/yr): 4.12E-02

Benefits from Avoided Direct Use of Fossil Fuels (during the life of the project):

Lifetime (MMTCO₂E): 4.60E-02
Average Annual (MMTCO₂E/yr): 3.06E-03

Landfill Characteristics

Open Year: 2003
Closure Year: 2028
Waste-In-Place at Closure (tons): 3,560,000
Average Waste Acceptance (tons/yr): 142,400
Average Depth of Landfill Waste (ft): 45
Area of LFG Wellfield to Supply Project (acres): 17

Landfill Gas Generation, Collection, and Utilization

Modeling Parameters for First-Order Decay Equation:

Methane Generation Rate, k (1/yr): 0.040
Methane Generation Capacity, L₀ (ft³/ton): 2,473
Methane Content of LFG: 50%

Generated During Project Lifetime (ft³/min):

Minimum: 384
Annual Average: 607
Maximum: 796

Collected During Project Lifetime (ft³/min):

Minimum: 246
Annual Average: 389
Maximum: 509

Project Size: Minimum
Design Flow Rate for Project (ft³/min): 246
Utilized by Project (ft³/min):

Annual Average: 221

LFG Collection Efficiency: 64%

Financial Assumptions

Loan Lifetime (years): 10
Interest Rate: 8.0%
General Inflation Rate: 2.5% (applied to O&M costs)
Equipment Inflation Rate: 1.0%
Marginal Tax Rate: 35.0%
Discount Rate: 10.0%
Down Payment: 20.0%
Collection and Flaring Costs: Included
Direct Use Production and Sales Summary

Pipeline Length From Landfill to End User (mi): 10.0

LFG Average Utilization (million Btu/yr): 58,806 (during the life of the project)

Initial Year LFG Price ($/million Btu): 5

Price to Achieve Financial Goals ($/million Btu): 5 (determined by Financial Goals Calculator results)

Landfill Gas Generation, Collection, and Utilization Curve

Year

Average Annual Landfill Gas Flow Rate (ft³/min)

Gas Generation

Gas Collection

Gas Utilization
APPENDIX III
Engine Power Production Project Economics
**U.S. EPA Landfill Methane Outreach Program**

**Landfill Gas Energy Cost Model**

**LFGcost, Version 2.0**

**Summary Report**

**Landfill Name or Identifier:** LINGSHAN LANDFILL, JI MO CITY, SHANDONG PROVINCE

**LFGE Project Type:** Standard Reciprocating Engine-Generator Set

**Date:** Friday, February 04, 2011

---

### Disclaimer:
LFGcost is a landfill gas energy project cost estimating tool developed for EPA's LMOP. LFGcost estimates landfill gas generation rates using a first-order decay equation. This equation is used to estimate generation potential but cannot be considered an absolute predictor of the rate of landfill gas generation. Variations in the rate and types of incoming waste, site operating conditions, and moisture and temperature conditions may provide substantial variations in the actual rates of generation.

The costs that are estimated by LFGcost are based on typical project designs and for typical landfill situations. The model attempts to include all equipment, site work, permits, operating activities, and maintenance that would normally be required for constructing and operating a typical project. However, individual landfills may require unique design modifications which would add to the cost estimated by LFGcost.

Analyses performed using LFGcost are considered preliminary and should be used for guidance only. A detailed final feasibility assessment should be conducted by qualified landfill gas professionals prior to preparing a system design, initiating construction, purchasing materials, or entering into agreements to provide or purchase energy from a landfill gas project.

### Summary Results

**Project Start Year:** 2012

**Project End Year:** 2026

**Project Type:** Standard Reciprocating Engine-Generator Set

**Financial Results:**

- **Net Present Value:** ($901,955) (at year of construction)
- **Internal Rate of Return:** -8%
- **Net Present Value Payback (yrs):** None (years after operation begins)
- **Installed Capital Costs:**
  - Gas Collection and Flare: $540,740
  - Gas Compression/Treatment, Engine/Generator, Site Work, and housings: $1,092,970
  - Electrical Interconnect Equipment: $257,575
  - Total Capital Costs: $1,891,285
- **O&M Costs:** $181,928 (for initial year of operation)

These financial results include the costs associated with the gas collection and flaring system.
Environmental Benefits

Benefits from Collecting and Destroying Methane (during the life of the project):

<table>
<thead>
<tr>
<th>Lifetime</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(million ft$^3$ methane)</td>
<td>1,533</td>
<td></td>
</tr>
<tr>
<td>(MMTCO$_2$E)</td>
<td>6.18E-01</td>
<td></td>
</tr>
</tbody>
</table>

Average Annual

| (million ft$^3$ methane/yr): | 102        |            |
| (MMTCO$_2$E/yr):            | 4.12E-02   |            |

Benefits from Avoided Electricity Generation from Fossil Fuels (during the life of the project):

| Lifetime (MMTCO$_2$E):      | 5.40E-02   |            |
| Average Annual (MMTCO$_2$E/yr): | 3.60E-03 |            |

Landfill Characteristics

Open Year: 2003
Closure Year: 2028
Waste-In-Place at Closure (tons): 3,560,000
Average Waste Acceptance (tons/yr): 142,400
Average Depth of Landfill Waste (ft): 45
Area of LFG Wellfield to Supply Project (acres): 17

Landfill Gas Generation, Collection, and Utilization

Modeling Parameters for First-Order Decay Equation:

| Methane Generation Rate, k (1/yr): | 0.040  |
| Methane Generation Capacity, L$_o$ (ft$^3$/ton): | 2,473  |
| Methane Content of LFG: | 50%    |

Generated During Project Lifetime (ft$^3$/min):

| Minimum: | 384     |
| Annual Average: | 607     |
| Maximum: | 796     |

Collected During Project Lifetime (ft$^3$/min):

| Minimum: | 246     |
| Annual Average: | 389     |
| Maximum: | 509     |

Project Size:
Minimum

Design Flow Rate for Project (ft$^3$/min): 246

Utilized by Project (ft$^3$/min):

| Annual Average: | 228     |

LFG Collection Efficiency: 64%

Financial Assumptions

Loan Lifetime (years): 10
Interest Rate: 8.0%

General Inflation Rate: 2.5% (applied to O&M costs)
Equipment Inflation Rate: 1.0%
Marginal Tax Rate: 35.0%
Discount Rate: 10.0%
Down Payment: 20.0%
Collection and Flaring Costs: Included
Electricity Production and Sales Summary

Total Generation Capacity (kW): 663

Average Generation (million kWh/yr): 5.023 (during the life of the project)

Initial Year Electricity Price ($/kWh): 0.06

Price to Achieve Financial Goals ($/kWh): 0.0107 (determined by Financial Goals Calculator results)

Landfill Gas Generation, Collection, and Utilization Curve
U.S. EPA Landfill Methane Outreach Program

Landfill Gas Energy Cost Model
LFGcost, Version 2.0
Summary Report

Landfill Name or Identifier: LINGSHAN LANDFILL, JI MO CITY, SHANDONG PROVINCE

LFGE Project Type: Standard Reciprocating Engine-Generator Set

Date: Friday, February 04, 2011

Disclaimer:
LFGcost is a landfill gas energy project cost estimating tool developed for EPA's LMOP. LFGcost estimates landfill gas generation rates using a first-order decay equation. This equation is used to estimate generation potential but cannot be considered an absolute predictor of the rate of landfill gas generation. Variations in the rate and types of incoming waste, site operating conditions, and moisture and temperature conditions may provide substantial variations in the actual rates of generation.

The costs that are estimated by LFGcost are based on typical project designs and for typical landfill situations. The model attempts to include all equipment, site work, permits, operating activities, and maintenance that would normally be required for constructing and operating a typical project. However, individual landfills may require unique design modifications which would add to the cost estimated by LFGcost.

Analyses performed using LFGcost are considered preliminary and should be used for guidance only. A detailed final feasibility assessment should be conducted by qualified landfill gas professionals prior to preparing a system design, initiating construction, purchasing materials, or entering into agreements to provide or purchase energy from a landfill gas project.

Summary Results

Project Start Year: 2012
Project End Year: 2026
Project Type: Standard Reciprocating Engine-Generator Set

Financial Results:

- Net Present Value: ($4,067) (at year of construction)
- Internal Rate of Return: 10%
- Net Present Value Payback (yrs): None (years after operation begins)
- Installed Capital Costs:
  - Gas Collection and Flare: $540,740
  - Gas Compression/Treatment, Engine/Generator, Site Work, and Houings: $1,092,970
  - Electrical Interconnect Equipment: $257,575
- Total Capital Costs: $1,891,285
- O&M Costs: $181,928 (for initial year of operation)

These financial results include the costs associated with the gas collection and flaring system.
Environmental Benefits

Benefits from Collecting and Destroying Methane (during the life of the project):

Lifetime:
- (million ft$^3$ methane): 1,533
- (MMTCO$_2$E): 6.18E-01

Average Annual:
- (million ft$^3$ methane/yr): 102
- (MMTCO$_2$E/yr): 4.12E-02

Benefits from Avoided Electricity Generation from Fossil Fuels (during the life of the project):

Lifetime (MMTCO$_2$E):
- 5.40E-02

Average Annual (MMTCO$_2$E/yr):
- 3.60E-03

Landfill Characteristics

Open Year: 2003
Closure Year: 2028
Waste-In-Place at Closure (tons): 3,560,000
Average Waste Acceptance (tons/yr): 142,400
Average Depth of Landfill Waste (ft): 45
Area of LFG Wellfield to Supply Project (acres): 17

Landfill Gas Generation, Collection, and Utilization

Modeling Parameters for First-Order Decay Equation:
- Methane Generation Rate, k (1/yr): 0.040
- Methane Generation Capacity, L$_o$ (ft$^3$/ton): 2,473
- Methane Content of LFG: 50%

Generated During Project Lifetime (ft$^3$/min):
- Minimum: 384
- Annual Average: 607
- Maximum: 796

Collected During Project Lifetime (ft$^3$/min):
- Minimum: 246
- Annual Average: 389
- Maximum: 509

Project Size: Minimum

Design Flow Rate for Project (ft$^3$/min): 246

Utilized by Project (ft$^3$/min):
- Annual Average: 228

LFG Collection Efficiency: 64%

Financial Assumptions

Loan Lifetime (years): 10
Interest Rate: 8.0%

General Inflation Rate: 2.5% (applied to O&M costs)
Equipment Inflation Rate: 1.0%
Marginal Tax Rate: 35.0%
Discount Rate: 10.0%
Down Payment: 20.0%
Collection and Flaring Costs: Included
**Electricity Production and Sales Summary**

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Generation Capacity (kW)</td>
<td>663</td>
</tr>
<tr>
<td>Average Generation (million kWh/yr)</td>
<td>5.023</td>
</tr>
<tr>
<td>(during the life of the project)</td>
<td></td>
</tr>
<tr>
<td>Initial Year Electricity Price ($/kWh)</td>
<td>0.06</td>
</tr>
<tr>
<td>Price to Achieve Financial Goals ($/kWh)</td>
<td>0.0107</td>
</tr>
<tr>
<td>(determined by Financial Goals Calculator results)</td>
<td></td>
</tr>
</tbody>
</table>

**Landfill Gas Generation, Collection, and Utilization Curve**

![Landfill Gas Generation, Collection, and Utilization Curve](image-url)
U.S. EPA Landfill Methane Outreach Program

Landfill Gas Energy Cost Model

LFGcost, Version 2.0

Summary Report

Landfill Name or Identifier: LINGSHAN LANDFILL, JI MO CITY, SHANDONG PROVINCE

LFGE Project Type: Standard Reciprocating Engine-Generator Set

Date: Friday, February 04, 2011

Disclaimer:
LFGcost is a landfill gas energy project cost estimating tool developed for EPA's LMOP. LFGcost estimates landfill gas generation rates using a first-order decay equation. This equation is used to estimate generation potential but can not be considered an absolute predictor of the rate of landfill gas generation. Variations in the rate and types of incoming waste, site operating conditions, and moisture and temperature conditions may provide substantial variations in the actual rates of generation.

The costs that are estimated by LFGcost are based on typical project designs and for typical landfill situations. The model attempts to include all equipment, site work, permits, operating activities, and maintenance that would normally be required for constructing and operating a typical project. However, individual landfills may require unique design modifications which would add to the cost estimated by LFGcost.

Analyses performed using LFGcost are considered preliminary and should be used for guidance only. A detailed final feasibility assessment should be conducted by qualified landfill gas professionals prior to preparing a system design, initiating construction, purchasing materials, or entering into agreements to provide or purchase energy from a landfill gas project.

Summary Results

Project Start Year: 2012

Project End Year: 2026

Project Type: Standard Reciprocating Engine-Generator Set

Financial Results:

- Net Present Value: $738,754 (at year of construction)
- Internal Rate of Return: 23%
- Net Present Value Payback (yrs): 8 (years after operation begins)
- Installed Capital Costs:
  - Gas Collection and Flare: $540,740
  - Gas Compression/Treatment, Engine/Generator, Site Work, and housings: $1,092,970
  - Electrical Interconnect Equipment: $257,575
  - Total Capital Costs: $1,891,285
- O&M Costs: $181,928 (for initial year of operation)

These financial results include the costs associated with the gas collection and flaring system.
Environmental Benefits

Benefits from Collecting and Destroying Methane (during the life of the project):

- **Lifetime**
  - (million ft³ methane): 1,533
  - (MMTCO₂E): 6.18E-01

- **Average Annual**
  - (million ft³ methane/yr): 102
  - (MMTCO₂E/yr): 4.12E-02

Benefits from Avoided Electricity Generation from Fossil Fuels (during the life of the project):

- **Lifetime (MMTCO₂E):** 5.40E-02
- **Average Annual (MMTCO₂E/yr):** 3.60E-03

Landfill Characteristics

- **Open Year:** 2003
- **Closure Year:** 2028
- **Waste-In-Place at Closure (tons):** 3,560,000
- **Average Waste Acceptance (tons/yr):** 142,400
- **Average Depth of Landfill Waste (ft):** 45
- **Area of LFG Wellfield to Supply Project (acres):** 17

Landfill Gas Generation, Collection, and Utilization

Modeling Parameters for First-Order Decay Equation:

- Methane Generation Rate, k (1/yr): 0.040
- Methane Generation Capacity, L₀ (ft³/ton): 2,473
- Methane Content of LFG: 50%

Generated During Project Lifetime (ft³/min):

- Minimum: 384
- Annual Average: 607
- Maximum: 796

Collected During Project Lifetime (ft³/min):

- Minimum: 246
- Annual Average: 389
- Maximum: 509

Project Size:

- Minimum: Minimum

Design Flow Rate for Project (ft³/min): 246

Utilized by Project (ft³/min):

- Annual Average: 228

LFG Collection Efficiency: 64%

Financial Assumptions

- **Loan Lifetime (years):** 10
- **Interest Rate:** 8.0%
- **General Inflation Rate:** 2.5% *(applied to O&M costs)*
- **Equipment Inflation Rate:** 1.0%
- **Marginal Tax Rate:** 35.0%
- **Discount Rate:** 10.0%
- **Down Payment:** 20.0%
- **Collection and Flaring Costs:** Included
Electricity Production and Sales Summary

Total Generation Capacity (kW): 663
Average Generation (million kWh/yr): 5.023 (during the life of the project)
Initial Year Electricity Price ($/kWh): 0.06
Price to Achieve Financial Goals ($/kWh): 0.0107 (determined by Financial Goals Calculator results)

Landfill Gas Generation, Collection, and Utilization Curve
APPENDIX IV
Small Engine Power Production Project Economics
U.S. EPA Landfill Methane Outreach Program

Landfill Gas Energy Cost Model
LFGcost, Version 2.0
Summary Report

Landfill Name or Identifier: LINGSHAN LANDFILL, JI MO CITY, SHANDONG PROVINCE

LFGE Project Type: Small Engine-Generator Set

Date: Friday, February 04, 2011

Disclaimer:
LFGcost is a landfill gas energy project cost estimating tool developed for EPA's LMOP. LFGcost estimates landfill gas generation rates using a first-order decay equation. This equation is used to estimate generation potential but cannot be considered an absolute predictor of the rate of landfill gas generation. Variations in the rate and types of incoming waste, site operating conditions, and moisture and temperature conditions may provide substantial variations in the actual rates of generation.

The costs that are estimated by LFGcost are based on typical project designs and for typical landfill situations. The model attempts to include all equipment, site work, permits, operating activities, and maintenance that would normally be required for constructing and operating a typical project. However, individual landfills may require unique design modifications which would add to the cost estimated by LFGcost.

Analyses performed using LFGcost are considered preliminary and should be used for guidance only. A detailed final feasibility assessment should be conducted by qualified landfill gas professionals prior to preparing a system design, initiating construction, purchasing materials, or entering into agreements to provide or purchase energy from a landfill gas project.

Summary Results

Project Start Year: 2012
Project End Year: 2026
Project Type: Small Engine-Generator Set

Financial Results:

- Net Present Value: ($1,213,007) (at year of construction)
- Internal Rate of Return: -36%
- Net Present Value Payback (yrs): None (years after operation begins)
- Installed Capital Costs: $1,511,062
- Gas Collection and Flare: $540,740
- Gas Compression/Treatment, Engine/Generator, Site Work, Housings, and Electrical Interconnect Equipment: $970,321
- Total Capital Costs: $1,511,062
- O&M Costs: $151,056 (for initial year of operation)

These financial results include the costs associated with the gas collection and flaring system.
Environmental Benefits

Benefits from Collecting and Destroying Methane (during the life of the project):

- **Lifetime**
  - (million ft³ methane): 1,533
  - (MMTCO₂E): 6.18E-01
- **Average Annual**
  - (million ft³ methane/yr): 102
  - (MMTCO₂E/yr): 4.12E-02

Benefits from Avoided Electricity Generation from Fossil Fuels (during the life of the project):

- **Lifetime (MMTCO₂E):** 3.30E-02
- **Average Annual (MMTCO₂E/yr):** 2.20E-03

Landfill Characteristics

- **Open Year:** 2003
- **Closure Year:** 2028
- **Waste-In-Place at Closure (tons):** 3,560,000
- **Average Waste Acceptance (tons/yr):** 142,400
- **Average Depth of Landfill Waste (ft):** 45
- **Area of LFG Wellfield to Supply Project (acres):** 17

Landfill Gas Generation, Collection, and Utilization

Modeling Parameters for First-Order Decay Equation:

- Methane Generation Rate, k (1/yr): 0.040
- Methane Generation Capacity, L₀ (ft³/ton): 2,473
- Methane Content of LFG: 50%

Generated During Project Lifetime (ft³/min):

- Minimum: 384
- Annual Average: 607
- Maximum: 796

Collected During Project Lifetime (ft³/min):

- Minimum: 246
- Annual Average: 389
- Maximum: 509

Project Size:

- Minimum

Design Flow Rate for Project (ft³/min):

- 246

Utilized by Project (ft³/min):

- Annual Average: 228

LFG Collection Efficiency:

- 64%

Financial Assumptions

- Loan Lifetime (years): 10
- Interest Rate: 8.0%
- General Inflation Rate: 2.5% \( (\text{applied to O&M costs}) \)
- Equipment Inflation Rate: 1.0%
- Marginal Tax Rate: 35.0%
- Discount Rate: 10.0%
- Down Payment: 20.0%
- Collection and Flaring Costs: Included
Electricity Production and Sales Summary

Total Generation Capacity (kW): 409
Average Generation (million kWh/yr): 3.069 (during the life of the project)
Initial Year Electricity Price ($/kWh): 0.06
Price to Achieve Financial Goals ($/kWh): 0.0107 (determined by Financial Goals Calculator results)

Landfill Gas Generation, Collection, and Utilization Curve
U.S. EPA Landfill Methane Outreach Program

Landfill Gas Energy Cost Model
LFGcost, Version 2.0

Summary Report

Landfill Name or Identifier: LINGSHAN LANDFILL, JI MO CITY, SHANDONG PROVINCE

LFGE Project Type: Small Engine-Generator Set

Date: Friday, February 04, 2011

Disclaimer:
LFGcost is a landfill gas energy project cost estimating tool developed for EPA's LMOP. LFGcost estimates landfill gas generation rates using a first-order decay equation. This equation is used to estimate generation potential but cannot be considered an absolute predictor of the rate of landfill gas generation. Variations in the rate and types of incoming waste, site operating conditions, and moisture and temperature conditions may provide substantial variations in the actual rates of generation.

The costs that are estimated by LFGcost are based on typical project designs and for typical landfill situations. The model attempts to include all equipment, site work, permits, operating activities, and maintenance that would normally be required for constructing and operating a typical project. However, individual landfills may require unique design modifications which would add to the cost estimated by LFGcost.

Analyses performed using LFGcost are considered preliminary and should be used for guidance only. A detailed final feasibility assessment should be conducted by qualified landfill gas professionals prior to preparing a system design, initiating construction, purchasing materials, or entering into agreements to provide or purchase energy from a landfill gas project.

Summary Results

Project Start Year: 2012
Project End Year: 2026
Project Type: Small Engine-Generator Set

Financial Results:

Net Present Value: ($222,683) (at year of construction)
Internal Rate of Return: 5%
Net Present Value Payback (yrs): None (years after operation begins)
Installed Capital Costs:
Gas Collection and Flare: $540,740
Gas Compression/Treatment, Engine/Generator, Site Work, Housings, and Electrical Interconnect Equipment: $970,321
Total Capital Costs: $1,511,062
O&M Costs: $151,056 (for initial year of operation)

These financial results include the costs associated with the gas collection and flaring system.
Environmental Benefits

Benefits from Collecting and Destroying Methane (during the life of the project):

<table>
<thead>
<tr>
<th>Lifetime</th>
<th>(million ft³ methane):</th>
<th>1,533</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(MMTCO₂E):</td>
<td>6.18E-01</td>
</tr>
</tbody>
</table>

Average Annual

| (million ft³ methane/yr): | 102 |
| (MMTCO₂E/yr):             | 4.12E-02 |

Benefits from Avoided Electricity Generation from Fossil Fuels (during the life of the project):

| Lifetime (MMTCO₂E):      | 3.30E-02 |
| Average Annual (MMTCO₂E/yr): | 2.20E-03 |

Landfill Characteristics

Open Year: 2003
Closure Year: 2028
Waste-In-Place at Closure (tons): 3,560,000
Average Waste Acceptance (tons/yr): 142,400
Average Depth of Landfill Waste (ft): 45
Area of LFG Wellfield to Supply Project (acres): 17

Landfill Gas Generation, Collection, and Utilization

Modeling Parameters for First-Order Decay Equation:
- Methane Generation Rate, k (1/yr): 0.040
- Methane Generation Capacity, L₀ (ft³/ton): 2,473
- Methane Content of LFG: 50%

Generated During Project Lifetime (ft³/min):
- Minimum: 384
- Annual Average: 607
- Maximum: 796

Collected During Project Lifetime (ft³/min):
- Minimum: 246
- Annual Average: 389
- Maximum: 509

Project Size: Minimum
Design Flow Rate for Project (ft³/min): 246
Utilized by Project (ft³/min):
- Annual Average: 228

LFG Collection Efficiency: 64%

Financial Assumptions

Loan Lifetime (years): 10
Interest Rate: 8.0%
General Inflation Rate: 2.5% (applied to O&M costs)
Equipment Inflation Rate: 1.0%
Marginal Tax Rate: 35.0%
Discount Rate: 10.0%
Down Payment: 20.0%
Collection and Flaring Costs: Included
Electricity Production and Sales Summary

Total Generation Capacity (kW): 409

Average Generation (million kWh/yr): 3.069 (during the life of the project)

Initial Year Electricity Price ($/kWh): 0.06

Price to Achieve Financial Goals ($/kWh): 0.0107 (determined by Financial Goals Calculator results)

Landfill Gas Generation, Collection, and Utilization Curve
U.S. EPA Landfill Methane Outreach Program

Landfill Gas Energy Cost Model
LFGcost, Version 2.0
Summary Report

Landfill Name or Identifier: LINGSHAN LANDFILL, JI MO CITY, SHANDONG PROVINCE

LFGE Project Type: Small Engine-Generator Set

Date: Friday, February 04, 2011

Disclaimer:
LFGcost is a landfill gas energy project cost estimating tool developed for EPA's LMOP. LFGcost estimates landfill gas generation rates using a first-order decay equation. This equation is used to estimate generation potential but cannot be considered an absolute predictor of the rate of landfill gas generation. Variations in the rate and types of incoming waste, site operating conditions, and moisture and temperature conditions may provide substantial variations in the actual rates of generation.

The costs that are estimated by LFGcost are based on typical project designs and for typical landfill situations. The model attempts to include all equipment, site work, permits, operating activities, and maintenance that would normally be required for constructing and operating a typical project. However, individual landfills may require unique design modifications which would add to the cost estimated by LFGcost.

Analyses performed using LFGcost are considered preliminary and should be used for guidance only. A detailed final feasibility assessment should be conducted by qualified landfill gas professionals prior to preparing a system design, initiating construction, purchasing materials, or entering into agreements to provide or purchase energy from a landfill gas project.

Summary Results

Project Start Year: 2012
Project End Year: 2026
Project Type: Small Engine-Generator Set

Financial Results:

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net Present Value:</td>
<td>$518,401</td>
<td>(at year of construction)</td>
</tr>
<tr>
<td>Internal Rate of Return:</td>
<td>21%</td>
<td></td>
</tr>
<tr>
<td>Net Present Value Payback (yrs):</td>
<td>10</td>
<td>(years after operation begins)</td>
</tr>
<tr>
<td>Installed Capital Costs:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas Collection and Flare:</td>
<td>$540,740</td>
<td></td>
</tr>
<tr>
<td>Gas Compression/Treatment, Engine/Generator, Site Work, Housings, and Electrical Interconnect Equipment:</td>
<td>$970,321</td>
<td></td>
</tr>
<tr>
<td>Total Capital Costs:</td>
<td>$1,511,062</td>
<td></td>
</tr>
<tr>
<td>O&amp;M Costs:</td>
<td>$151,056</td>
<td>(for initial year of operation)</td>
</tr>
</tbody>
</table>

These financial results include the costs associated with the gas collection and flaring system.
Environmental Benefits

Benefits from Collecting and Destroying Methane (during the life of the project):

Lifetime

(million ft³ methane): 1,533
(MMTCO₂E): 6.18E-01

Average Annual

(million ft³ methane/yr): 102
(MMTCO₂E/yr): 4.12E-02

Benefits from Avoided Electricity Generation from Fossil Fuels (during the life of the project):

Lifetime (MMTCO₂E): 3.30E-02
Average Annual (MMTCO₂E/yr): 2.20E-03

Landfill Characteristics

Open Year: 2003
Closure Year: 2028
Waste-In-Place at Closure (tons): 3,560,000
Average Waste Acceptance (tons/yr): 142,400
Average Depth of Landfill Waste (ft): 45
Area of LFG Wellfield to Supply Project (acres): 17

Landfill Gas Generation, Collection, and Utilization

Modeling Parameters for First-Order Decay Equation:

Methane Generation Rate, k (1/yr): 0.040
Methane Generation Capacity, L₀ (ft³/ton): 2,473
Methane Content of LFG: 50%

Generated During Project Lifetime (ft³/min):

Minimum: 384
Annual Average: 607
Maximum: 796

Collected During Project Lifetime (ft³/min):

Minimum: 246
Annual Average: 389
Maximum: 509

Project Size: Minimum
Design Flow Rate for Project (ft³/min): 246
Utilized by Project (ft³/min):

Annual Average: 228
LFG Collection Efficiency: 64%

Financial Assumptions

Loan Lifetime (years): 10
Interest Rate: 8.0%
General Inflation Rate: 2.5% (applied to O&M costs)
Equipment Inflation Rate: 1.0%
Marginal Tax Rate: 35.0%
Discount Rate: 10.0%
Down Payment: 20.0%
Collection and Flaring Costs: Included
**Electricity Production and Sales Summary**

Total Generation Capacity (kW):
409

Average Generation (million kWh/yr):
3.069 (during the life of the project)

Initial Year Electricity Price ($/kWh):
0.06

Price to Achieve Financial Goals ($/kWh):
0.0107 (determined by Financial Goals Calculator results)

---

**Landfill Gas Generation, Collection, and Utilization Curve**

- Gas Generation
- Gas Collection
- Gas Utilization

---

REPORT - 3
APPENDIX V
Selected Photos
View of Lingshan Landfill Looking North towards Leachate Treatment Facility

View of Lingshan Landfill Looking South
View of Weigh Station

View of Base Liner in Phase I Area
View Showing Base of Waste is Dry – Phase I Area

View of Exposed Refuse – Active Phase I Area
View of Cover HDPE Liner (Sewn Not Heat Fusion Welded)

Vent Pipe in Expose Refuse – Phase I Area
View of Vent Pipe in Phase I Area with Cover

Phase I Vent Pipe Monitoring
View of Leachate Drainage by Gravity Flow into the Holding Pond, and
View of Anaerobic Leachate Treatment Pond

View of Leachate Treatment Area
View of Leachate Treatment Canisters Containing Porcelain Columns

Group Photo

Mr. Sun Wei-min, Lingshan Landfill Manager (left); Mr. Mr. Jiang Fu-shan, former department head of Jimo City Landscape Management Bureau (middle); Mr. Haiyan Xu, China Environmental Sanitation Engineering Technology (right)