Assessment of Landfill Gas Potential: Weihai City Landfill

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EXECUTIVE SUMMARY

The Weihai City Landfill is owned by the Weihai City Construction Commission and operated by the Weihai City Landfill Site Management Department. As the agency responsible for monitoring compliance in the Province, the Shandong Province Construction Bureau (SPCB) provides regulatory oversight to all landfills in Shandong. The Shandong Province Construction and Development Research Institute (SPCDRI), a subsidiary of SPCB, is responsible for investigating the potential for energy recovery and utilization at the Weihai City Landfill.

The site began accepting waste in December 2000 and currently accepts approximately 230,000 tonnes per year of municipal waste from Weihai City. As of December 2007, the site contained almost 1.35 million tonnes of waste. It is designed to operate until 2026, but the amount of waste accepted is expected to drop after 2010 when some of the waste will be diverted to a planned municipal waste incinerator.

Under contract to the United States Environmental Protection Agency (U.S. EPA), Eastern Research Group, Inc. (ERG) and Organic Waste Technologies (H.K.) Limited (OWT) completed an initial assessment of the Weihai City Landfill’s potential to generate methane. Analysis of the data provided by the Weihai City Landfill Site Management Department indicates that the site could be currently emitting between 572 and 1,020 standard cubic feet per minute (scfm) (972 and 1,733 m³/hr) of landfill gas, containing approximately 50% methane. This rate could reach a peak of approximately between 711 and 1,210 scfm (1,208 and 2,056 m³/hr) in 2010 before the planned waste incinerator commences operation. Due to the current construction techniques and materials employed at the site, not all of this landfill gas will be available for collection and utilization. We estimate that the amount of landfill gas that could be collected for beneficial use is currently 372 scfm (632 m³/hr) and will peak at 462 scfm (785 m³/hr) in 2010. This is intended to be a slightly conservative but realistic estimate of recoverable gas.

Moderate quantities of energy available from the landfill gas present a fair opportunity for development of landfill gas to energy using Weihai City Landfill’s gas. Direct use of the gas (e.g., at the planned waste incineration plant or the existing medical waste incineration plant) appears to be the most feasible option for utilization of landfill gas. The introduction and implementation of proper solid waste management practices will improve gas collection efficiency. Internationally accepted solid waste management practices that promote LFG generation and collection typically comprise waste placement methods, compaction rates, daily, intermediate and final cover, proper grading and drainage, and effective leachate and gas management systems. To achieve reasonable levels of gas recovery necessary for a successful energy project, optimization of gas collection system efficiency requires not only a well designed, installed, and operated gas collection system; but also prevention of potential air ingress and subsurface combustion.

The economic feasibility of LFG energy projects is enhanced by the ability to take advantage of renewable incentives and greenhouse gas (carbon) reduction incentives. However, for the Weihai City Landfill, the capacity of an energy project to generate greenhouse gas credit is limited due to the existence of an operating enclosed flare that can handle all landfill gas expected to be recovered at the site. This will likely prevent the landfill from claiming direct methane reduction credits from destroying the landfill methane, but a utilization project (electricity or direct use) would still be eligible for greenhouse gas reduction credits for displacing fossil fuel combustion. The economic feasibility of an energy project increases moderately as the market value of emission reduction credits increases and/or period of time over which emission reduction credits are available increases.
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 quality gas that can be used to meet local energy needs, preparing assessment reports, and possibly conducting training on landfill gas energy and the ways to develop landfill methane projects. To support these activities, the U.S. EPA has contracted with two companies, Eastern Research Group, Inc. (ERG) and Organic Waste Technologies (H.K.) Ltd. (OWT).

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. OWT has visited numerous landfill sites to collect information on landfill design, waste volume, waste composition and gas composition, and make observations to assess the gas generation and recovery potential of the landfill sites. Information was also collected, where available, on the local energy users that could potentially be interested in using the energy produced by the landfill.

This assessment report summarizes the findings of the site visit to Weihai City Landfill in Weihai City, Shandong Province, China. This report includes a brief assessment of the gas production potential of the landfill, and examines 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 project developers as they assess the potential of a landfill methane energy project at the site.

The site visit included non-invasive analysis of the landfill gas, as well as a “walk over” inspection of the landfill, including observation of gas and leachate control measures, containment technology, topography and general condition / operation of the landfill. Physical investigatory work on the site was limited to site reconnaissance and monitoring appropriate locations for gas quality (methane, carbon dioxide, and oxygen).

2. PROJECT LIMITATIONS

The information and predictions contained within this assessment report are based on the data provided by the site operator. 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.

Note that landfill conditions will vary with changes in waste input, management practices, engineering practices, and environmental conditions (particularly rainfall and temperature). Therefore, the quantity and quality of landfill gas extracted from the landfill site in the future may vary from the values predicted in this report, which are based on conditions observed during the site visit.

The site currently manages landfill gas via a combined active extraction and passive venting system. The site implemented a partial gas collection and flaring system in 2006 but no utilization system has been installed. The capital and O&M cost, return on investment, and net present value associated with installing a comprehensive system at the Weihai City Landfill 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 from LFGcost approximate the costs and revenues in China, but no warranty is given or implied on the accuracy of these US and Chinese data.

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

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

3. LANDFILL GAS

Landfills produce biogas (normally called landfill gas) as organic materials decompose under anaerobic (without oxygen) conditions. Landfill gas is composed of approximately equal parts methane and carbon dioxide, with a smaller percentage of oxygen, nitrogen, and water vapor, as well as trace concentrations of volatile organic compounds (VOCs) and hazardous air pollutants (HAPs). Both of the two primary constituents of landfill gas (methane and carbon dioxide) are considered to be greenhouse gases (GHG), which contribute to global warming. However, the Intergovernmental Panel on Climate Change (IPCC) does not consider the carbon dioxide specifically present in raw landfill gas to be a GHG. IPCC considers the carbon dioxide in landfill gas to be “biogenic” and thus, part of the natural carbon cycle. As such, only the methane content of the gas is included in calculations of atmospheric GHG emissions.

Methane is a more potent GHG than carbon dioxide (CO₂), with a global warming potential over 20 times that of CO₂. Therefore, the capture and combustion of methane (transforming it to carbon dioxide and water) in a flare, an engine generator or other devices, results in a substantial net reduction of GHG emissions. 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.

There are two natural pathways by which landfill gas can leave a landfill: by migration into the adjacent subsurface and by venting through the landfill cover system. In both cases, without capture and control, the landfill gas (containing methane) will ultimately reach the atmosphere. The volume and rate of methane emissions from a landfill are a function of the total quantity of organic material buried in the landfill, the material’s age and moisture content, compaction techniques, temperature, and waste type and particle size. While the methane emission rate will decrease after a landfill is closed (as the organic fraction is depleted), a landfill will typically continue to emit methane for many (20 or more) years after its closure.

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. Landfill gas control systems are typically equipped with a combustion (or other treatment) device designed to destroy methane, VOCs, and HAPs prior to their emission to the atmosphere.

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 electrical generation using reciprocating engines and
direct heating projects at the Weihai City Landfill. Other utilization options (e.g. turbines and CHP
system) are also commercially available. However, observations made and constraints noted during the
site visit appear to favor a limited number of utilization options for further assessment.

4. LANDFILL DATA

A site visit was conducted on June 29, 2008. Prior to the site visit, the site operator was requested to
provide information on the waste inputs, engineering details, and environmental conditions of the site
via a questionnaire. Data provided has been edited into a standard format. Some data were verified or
information adjusted based on the results of site specific observations made during the visit. The
following paragraphs highlight the data obtained and analyzed for the Weihai City Landfill.

4.1. Site Location and Operation

The Weihai City Landfill is located southeast of Qianshuangdao Village, Huancui District, Weihai City,
Shandong Province, and is approximately 17 kilometers (km) from downtown Weihai City. The area is
generally rural and has no industrial facilities nearby, except for a medical waste incineration plant (in
operation since 2003) located less than 3-km to the northeast of the site (see Appendix III for an aerial
photo of the site, and Appendix IV for selected site photos).

The site has a footprint area of 32.36 hectares (Ha), and is situated in a valley that slopes downwards
from east to west. The designed capacity of the entire site is approximately 4.47 million cubic meters.
At the eastern side of the site, a waste dam has been constructed to retain waste and form a platform for
current and future waste placement.

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compliance in the Province, the Shandong Province Construction Bureau (SPCB) provides regulatory
oversight to all landfills in Shandong. The Shandong Province Construction and Development
Research Institute (SPCDRI), a subsidiary of SPCB, is responsible for investigating the potential for
energy recovery and utilization at the Weihai City Landfill.

4.2. Waste Inputs

The site accepts domestic waste mainly generated from Weihai City, which has a population of about
270,000. The site began accepting waste in December 2000, and has been designed with a 26-year site
life. During the visit, the site operator reported a current waste inflow of approximately 630 – 650
tonnes per day (equivalent to 229,950 – 237,250 tonnes per year). The site operator also reported that
as of December 2007, approximately 1.35 million tonnes of waste is in place.

A weighbridge was observed at the site and appeared to be in operation. According to the site
management, this has been used to weigh the incoming waste since 2006; whereas waste inflow was
estimated based on truck counts before 2006.
Annual waste input to the site is shown in Table 1.

Table 1 - Waste Input 2001 - 2007

<table>
<thead>
<tr>
<th>Year</th>
<th>Total Tonnes</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>127,832</td>
</tr>
<tr>
<td>2002</td>
<td>156,064</td>
</tr>
<tr>
<td>2003</td>
<td>189,719</td>
</tr>
<tr>
<td>2004</td>
<td>217,993</td>
</tr>
<tr>
<td>2005</td>
<td>217,835</td>
</tr>
<tr>
<td>2006</td>
<td>209,825</td>
</tr>
<tr>
<td>2007</td>
<td>229,455</td>
</tr>
<tr>
<td>Total</td>
<td>1,348,723</td>
</tr>
</tbody>
</table>

To be conservative, the lower end of the current range of daily waste input (630 tonnes per day) was used to estimate the 2008 waste input. The site operator indicated that a waste incineration plant with a treatment capacity of 600 tonnes per day is expected to commence operation in 2010. For the purpose of this assessment, the daily waste inflow to the site is assumed to grow at an annual rate of 4% (instead of the 5.24% annual growth assumed in the landfill design documents), with 600 tonnes diverted to the waste incinerator starting in 2010. Accordingly, the landfill will reach capacity during 2023, which is generally consistent with the 26-year design life.

The projected waste input from 2008 to closure is shown in Table 2.

Table 2 - Estimated Waste Input 2008 - 2023

<table>
<thead>
<tr>
<th>Year</th>
<th>Total Tonnes</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>229,950</td>
</tr>
<tr>
<td>2009</td>
<td>239,148</td>
</tr>
<tr>
<td>2010</td>
<td>29,714</td>
</tr>
<tr>
<td>2011</td>
<td>39,662</td>
</tr>
<tr>
<td>2012</td>
<td>50,009</td>
</tr>
<tr>
<td>2013</td>
<td>60,769</td>
</tr>
<tr>
<td>2014</td>
<td>71,960</td>
</tr>
<tr>
<td>2015</td>
<td>83,599</td>
</tr>
<tr>
<td>2016</td>
<td>95,702</td>
</tr>
<tr>
<td>2017</td>
<td>108,291</td>
</tr>
<tr>
<td>2018</td>
<td>121,382</td>
</tr>
<tr>
<td>2019</td>
<td>134,997</td>
</tr>
<tr>
<td>2020</td>
<td>149,157</td>
</tr>
<tr>
<td>2021</td>
<td>163,884</td>
</tr>
<tr>
<td>2022</td>
<td>179,199</td>
</tr>
<tr>
<td>2023</td>
<td>110,093</td>
</tr>
<tr>
<td>Total Future</td>
<td>1,867,517 Tonnes</td>
</tr>
<tr>
<td>TOTAL</td>
<td>3,216,240 Tonnes</td>
</tr>
</tbody>
</table>
5. **WASTE COMPOSITION**

The site management indicated that the waste deposited at the site is mainly municipal solid waste with an organic content of 78.39% and an inorganic content of 21.61%. Observations made during the site visit confirmed the dominant fraction of waste is organic.

6. **RECYCLING ACTIVITIES**

The site management indicated that there were scavenging activities on Saturdays and Sundays at the site. This was confirmed during the site visit which was on a Sunday; a group of 20 to 30 people were observed to recycle mainly plastics, fiber and glass. As the majority of the recycled materials are inert in nature, their removal from the waste should not have a noticeable effect on the site’s overall methane generation.

7. **SITE CONSTRUCTION**

The general conditions and engineering features of the site were examined during the site visit to confirm waste inflow and characteristic data, observe operational practices, and obtain gas quality monitoring data where available. The subsequent sections describe the pertinent features at the site.

7.1. **General Observations**

The site is constructed in a valley that slopes downwards from east to west; it is bounded to the south by farmland and to the north and east by hills.

There is little or no local industry and the surrounding area is generally residential. A medical waste incineration plant and the closest residence (Daxizhuang village) are located approximately 3-km and 1-km from the site, respectively.

7.2. **Environmental Data**

Average total annual rainfall is 727mm, and annual average temperature is 12.3°C. The site is therefore categorized as fairly dry, potentially reducing the rate of waste degradation.

7.3. **Waste Depth.**

It is indicated that the average depth of waste at the platform is approximately 45 m.

7.4. **Waste Placement.**

Waste was observed to be brought to the site in closed vehicles, offloaded in an approximately 200m² tipping area and spread around with a bulldozer. The site operator indicated that there are four bulldozers, three loaders and a BOMAG compactor for waste spreading and compaction. No compaction was observed to be carried out during the visit.

The waste density was reported to be 0.8 tonnes/m³. Based on the observed waste placement techniques, the reported density is reasonable.
7.5. Base Lining.

The site management reported that the site has a bottom liner that consists of a 2m thick layer of clay.

7.6. Capping Layer.

The current intermediate capping layers are constructed with natural soil stockpiles (excavated during site development and expansion). An intermediate soil layer is placed on top of the waste every 4 to 6 m deep; the current plan for intermediate cover does not include provisions for geo-synthetic materials. The thickness of daily soil cover varies between 30 and 50 cm.

During the June 2008 site visit, the soil covers appeared to be tight and well-constructed with well-graded soil. Moderate resistance to escape of landfill gas from the waste and to intrusion of air and surface water into the waste is expected.

7.7. Surface Water Management

A concrete surface water channel was observed running along the perimeter of the waste platform to divert stormwater away from the waste. Part of the channel was observed to have suffered some slight damage, probably caused by heavy equipment while placing rocks adjacent to the channel; the other parts of the channel were noticed in good condition. According to the site management, there are surface water channels at three other elevations.

No surface water drainage facilities were observed on the platform or the waste slope during the site visit. A surface water pond of about 100m² in size was noticed adjacent to the active tipping area, indicative of inadequate surface water drainage at the platform.

8. LEACHATE AND GAS

8.1. Leachate

Leachate is the liquid produced by contamination of water within the landfill site by a wide range of solutes resulting from the disposal and decomposition of waste (including organic and inorganic components) in landfills. The water content results from drainage of moisture from the original waste, water resulting from degradation, and surface water (rainfall) entering the site. Leachate is highly contaminated and usually has a very low concentration of dissolved oxygen.

A number of horizontal leachate drainage channels were constructed using perforated pipes prior to the deposit of waste. Leachate was designed to drain by gravity, making use of the site topography, to the leachate holding lagoon, which is constructed with concrete on top of natural bedrock. The lagoon surface is covered with HDPE liner for odor control purposes. The leachate drainage pipes, however, were reported to be clogged, with limited functionality.

As indicated by the site operator, about 150 m³ of leachate is collected daily and treated at the on-site leachate treatment plant that has a treatment capacity of 300 m³ per day. It is understood that the treatment processes include sedimentation, flocculants addition and biological filtering. However, during the site visit, the operator indicated that operation of the on-site treatment plant has been
suspended since 2006 due to unsatisfactory performance; instead, the leachate is sent to an offsite wastewater treatment plant. No leachate level measurement records were available for review during the site visit.

8.2. Gas

Landfill gas is managed at the Weihai City Landfill with a combined active extraction and passive venting system. The active extraction system includes 19 gas wells located on the waste slope and the western part of the platform, an inactive area where the landfill has reached interim grade; they cover approximately 40% of the waste area. The passive venting system consists of approximately 15 vents located on the eastern part of the platform, an active area where wastes are being placed.

The existing gas wells are constructed in 600mm diameter well borings with 200mm perforated HDPE pipes, with 600mm diameter metal casings extending approximately 3 meters above the ground surface. A typical active gas extraction well is shown in Photo 6 in Appendix IV. The collected gas is transferred to an enclosed flaring system through laterals, manifolds and a main header.

The design capacity of the flare is 1,000 m³/hr. During the site visit, the flare was observed to be operating at a relatively low flow rate of approximately 96 m³/hr. The low flow rate is believed to be the result of condensate blockages on the main header and lateral pipes, as evidenced by audible “slurping” in the pipes.

The passive vents, constructed with perforated HDPE pipes installed to a depth close to the base of the site, are located on the eastern part of the platform. Information regarding whether they intersect with the leachate collection system was not available. The vents are protected at the surface with a pile of rocks (see Photos 7 and 8). The passive vents are open to the atmosphere and gas from them is not routed to the flare.

Due to a lack of sampling ports on the gas wells, measurement of gas concentration was only conducted at passive vents (i.e., gas vents 1 through 4) using a Geotechnical Instruments GEM2000 gas analyzer. Measurement data are presented in Table 3 below. A calibration certificate for the analyzer is presented in Appendix II.

Gas monitoring results at vents 3 and 4 indicated methane concentrations typical of landfill gas (43% and 44% v/v), while the methane concentrations at Vents 1 and 2 are very low (less than 1%) to moderately low (approximately 18%). Vent 1 was located very close to the perimeter of the landfill where the thickness of the waste is relatively small, which may account for the very low methane concentration measured there. However, the ratio of oxygen to balance gas (mostly nitrogen) at all four vents is consistent with air mixing with landfill gas. Since the measurements were taken at passive vents where air was allowed to mix freely with landfill gas, it is difficult to draw conclusive results from these measurements regarding the quality of the gas generated within the landfill.
Table 3 – Gas Measurements Results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Gas Vent 1</th>
<th>Gas Vent 2</th>
<th>Gas Vent 3</th>
<th>Gas Vent 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH₄ (%)</td>
<td>0.3</td>
<td>18.2</td>
<td>43.1</td>
<td>44.0</td>
</tr>
<tr>
<td>CO₂ (%)</td>
<td>0.3</td>
<td>13.9</td>
<td>29.3</td>
<td>26.8</td>
</tr>
<tr>
<td>O₂ (%)</td>
<td>20.3</td>
<td>14.1</td>
<td>5.6</td>
<td>5.7</td>
</tr>
<tr>
<td>Balance Gas (%)</td>
<td>79.1</td>
<td>53.8</td>
<td>22.0</td>
<td>23.5</td>
</tr>
<tr>
<td>Atmospheric Pressure (mB)</td>
<td>996</td>
<td>996</td>
<td>996</td>
<td>996</td>
</tr>
<tr>
<td>Ambient Temperature (°C)</td>
<td>28.2</td>
<td>28.2</td>
<td>28.2</td>
<td>28.2</td>
</tr>
<tr>
<td>Gas Temperature (°C)</td>
<td>33.0</td>
<td>29.8</td>
<td>31.3</td>
<td>30.4</td>
</tr>
</tbody>
</table>

9. GAS MODELING

9.1. Emission Modeling

The estimation of emissions indicates the potential total landfill gas emissions from the site. This calculation should not be confused with the recoverable landfill gas which may be available for utilization. Recoverable landfill gas is estimated in the following section of this report.

The baseline for the estimated amount of methane generated by the site has been calculated with the use of the U.S. EPA LandGEM landfill gas model based on first order decay mathematics. The U.S. EPA LandGEM LFG Model is based on the following equation (Eqn.1):

Equation 1 - First Order Decay Model

\[ Q = \sum_{0}^{n} \frac{1}{%_{vol}} kML_0 e^{-k(t-t_{lag})} \]

Where:

- \( Q \): total quantity of landfill gas generated (Normal cubic meters)
- \( n \): total number of years modeled
- \( t \): time in years since the waste was deposited
- \( t_{lag} \): estimated lag time between deposition of waste and generation of methane.
- \( %_{vol} \): estimated volumetric percentage of methane in landfill gas
- \( L_0 \): estimated volume of methane generated per tonne of solid waste
- \( k \): estimated rate of decay of organic waste
- \( M \): mass of waste in place at year \( t \) (tonnes)

The dry organic fraction of waste (derived by subtracting the mass of water and inorganic waste components from the total mass) is used to calculate the quantity of landfill gas generated. For landfills where there is evidence of previous or on-going underground landfill fires, the gas producing potential of the waste may be further reduced to reflect losses in waste mass due to prior or anticipated future combustion.
When the amount of landfill gas being generated by the site has been theoretically determined, the following equation (Eqn. 2) can be used to estimate the effective number of tonnes of carbon dioxide equivalent being emitted by the site. This factor of 21 is used to estimate the greenhouse gas potential, in tonnes of carbon dioxide equivalent, resulting from the emission of methane [1].

**Equation 2 - Baseline GHG Emissions**

$$T_{CO_2eq.} = \%_{vol} \times 21 \times Q \times \rho_{CH_4}$$

Where:

- $T_{CO_2eq.}$: Total tonnes of carbon dioxide equivalent generated
- $\%_{vol}$: Estimated volumetric percentage of methane in landfill gas.
- $Q$: Total quantity of landfill gas from Eqn. 1 (Normal cubic meters)
- $\rho_{CH_4}$: Density of Methane = 0.0007168 tonnes / cubic meter


The values of the model parameters $L_0$ and $k$ depend on the available organic fraction, the temperature, and moisture content of the waste. Three values for these two variables are presented in Table 4. These values were based on previous experience with landfills in China and Asia, and represent the upper, average and lower estimates. The range of values for $L_0$ and $k$ brackets the appropriate conditions for the Weihai City Landfill and are common at other landfill sites in Asia, with similar moisture content and organic component of the waste. Similar range of values for $L_0$ and $k$ had been presented in 2003 in China [2]. The selected values are also consistent with similar China-specific information provided in other technical papers in 2006 [3].

Based on prior experiences with the use of theoretical models for LFG generation and recovery at other sites, the upper estimate for LFG generation and recovery is oftentimes optimistic, and therefore not conservative from a financial feasibility standpoint. The average estimate represents LFG generation to be expected for a landfill operating under average conditions (such as timely and adequate cover and compaction, appropriate liquid levels, etc.). For this assessment study where conservatism is desirable, the expected LFG recovery and financial performance are estimated based on the lower LFG generation estimate with appropriate collection efficiency.

Table 4 shows the model parameters used in the gas models.

**Table 4 - Model Input Parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L_0$ (Ultimate methane generation potential, in m³/tonne)</td>
<td>110</td>
<td>Upper estimate</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>Average estimate</td>
</tr>
<tr>
<td></td>
<td>90</td>
<td>Lower estimate</td>
</tr>
<tr>
<td>$k$ (Methane generation rate constant)</td>
<td>0.18</td>
<td>Upper estimate</td>
</tr>
<tr>
<td></td>
<td>0.14</td>
<td>Average estimate</td>
</tr>
<tr>
<td></td>
<td>0.10</td>
<td>Lower estimate</td>
</tr>
</tbody>
</table>
10. BASELINE RESULTS OF GAS MODEL

Results of the U.S. EPA LandGEM LFG Model (run with upper, average and lower estimates for k and L₀) are given in the following graph (Figure 1) and expected gas production rates for the next 20 years in Table 5.

Using values for k and L₀, the LandGEM Model estimates that the site should currently be producing between 572 and 1,020 scfm (972 and 1,733 m³/hr) of landfill gas at 50% methane and that this emission rate will rise to a peak of between approximately 711 and 1,210 scfm (1,208 and 2,056 m³/hr) in 2010.

The shape of the gas curve is unusual because of the expected decrease in the annual waste acceptance rate after 2010 when much of the waste stream will likely be diverted to the planned municipal waste incinerator. The predicted reduction in annual waste acceptance rate from 239,148 tonnes per year in 2009 to just 29,714 tonnes per year in 2010 (see table 2 for waste acceptance rates) is the cause of the abrupt drop in the gas production curve starting in 2011. The gradual rise in the gas production occurring between 2015 and 2023 is a result of gradual increases in waste acceptance rates from 2010 to 2022 (see table 2). The decline in gas production after 2024 is based on the prediction that the landfill will reach its capacity in 2023 and then stop accepting waste.
Figure 1 - Baseline Landfill Gas Emissions

Table 5 - Landfill Gas Model Results (LandGEM Model, @50% CH4)

<table>
<thead>
<tr>
<th>Year</th>
<th>LandGEM Upper Estimate (scfm)</th>
<th>LandGEM Average Estimate (scfm)</th>
<th>LandGEM Lower Estimate (scfm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>1,020</td>
<td>799</td>
<td>572</td>
</tr>
<tr>
<td>2009</td>
<td>1,118</td>
<td>886</td>
<td>643</td>
</tr>
<tr>
<td>2010</td>
<td>1,210</td>
<td>969</td>
<td>711</td>
</tr>
<tr>
<td>2011</td>
<td>1,045</td>
<td>867</td>
<td>660</td>
</tr>
<tr>
<td>2012</td>
<td>919</td>
<td>787</td>
<td>619</td>
</tr>
<tr>
<td>2013</td>
<td>825</td>
<td>726</td>
<td>587</td>
</tr>
<tr>
<td>2014</td>
<td>760</td>
<td>681</td>
<td>564</td>
</tr>
<tr>
<td>2015</td>
<td>718</td>
<td>652</td>
<td>550</td>
</tr>
<tr>
<td>2016</td>
<td>696</td>
<td>636</td>
<td>543</td>
</tr>
<tr>
<td>2017</td>
<td>692</td>
<td>633</td>
<td>543</td>
</tr>
<tr>
<td>2018</td>
<td>703</td>
<td>640</td>
<td>550</td>
</tr>
<tr>
<td>2019</td>
<td>728</td>
<td>658</td>
<td>564</td>
</tr>
<tr>
<td>2020</td>
<td>764</td>
<td>684</td>
<td>584</td>
</tr>
<tr>
<td>Year</td>
<td>LandGEM Upper Estimate (scfm)</td>
<td>LandGEM Average Estimate (scfm)</td>
<td>LandGEM Lower Estimate (scfm)</td>
</tr>
<tr>
<td>------</td>
<td>-------------------------------</td>
<td>--------------------------------</td>
<td>-------------------------------</td>
</tr>
<tr>
<td>2021</td>
<td>810</td>
<td>719</td>
<td>609</td>
</tr>
<tr>
<td>2022</td>
<td>866</td>
<td>761</td>
<td>641</td>
</tr>
<tr>
<td>2023</td>
<td>931</td>
<td>811</td>
<td>677</td>
</tr>
<tr>
<td>2024</td>
<td>905</td>
<td>796</td>
<td>673</td>
</tr>
<tr>
<td>2025</td>
<td>756</td>
<td>692</td>
<td>609</td>
</tr>
<tr>
<td>2026</td>
<td>631</td>
<td>602</td>
<td>551</td>
</tr>
<tr>
<td>2027</td>
<td>527</td>
<td>523</td>
<td>498</td>
</tr>
<tr>
<td>2028</td>
<td>440</td>
<td>455</td>
<td>451</td>
</tr>
</tbody>
</table>

11. ANTICIPATED COLLECTION EFFICIENCY

The estimate of landfill gas generation from the site does not imply that all the gas can be collected for combustion or flaring. Many engineering issues and the continued waste management operations at the site must be taken into account to assess the actual amount of gas that could be collected. These issues include landfill phasing, waste compaction and cover placement, gas management, condensate management, leachate management, and stormwater management.

For a well managed landfill, the phasing plan would allow the prompt installation of gas extraction systems to maximize gas collection, the waste would be compacted and covered in a timely manner to minimize air and water intrusion and to avoid aerobic decomposition of the waste, stormwater would be diverted away from the waste to minimize leachate generation, and generated leachate would be removed from the waste to promote gas generation and collection. Proper management of the gas and condensate collection system would optimize the amount of gas recovered. Typical LFG collection efficiencies could be as high as 80% or more for such a well-managed landfill; however, for a poorly managed site, it could be 20% or less.

With the existing gas collection system covering only approximately 40% of the landfilled waste, a lack of daily cover, and apparent condensate blockages in laterals and headers, the collection efficiency of the existing gas collection system is probably less than 25%. Information necessary for a detailed evaluation of the collection efficiency that can be anticipated or achieved at the Weihai City Landfill in the future was not available. However, if proper solid waste management practices are introduced and employed (if an energy project were to proceed at the site) it is reasonable to expect that a modest collection efficiency of 65% could be achieved.

Optimization of collection efficiency requires implementation and adherence to internationally accepted standards for solid waste management practices, which promote LFG generation and collection. These practices typically include waste compaction, daily cover, improved intermediate and final covers, proper drainage, and a properly designed, installed, and operated gas collection system.
12. CALCULATED GAS AVAILABILITY

Based on the above discussion, it is assumed for this assessment that approximately 65% of the landfill gas generated at the Weihai City Landfill could be recovered for utilization. For this assessment study where conservatism is desirable, the expected LFG recovery and financial performance are estimated based on the lower LFG generation estimate. Applying the 65% availability factor to the lower estimate in Table 5 gives an estimated available gas flow shown in Table 6.

Landfill methane has a calorific value of approximately 1,012 Btu/cf; however, because typical landfill gas contains approximately 50% combustible and 50% non-combustible compounds, the resultant thermal energy contained in landfill gas is approximately 506 Btu/cf.

Table 6 also shows the estimated available thermal energy.

Table 6 – Estimated Landfill Gas Recovery and Available Thermal Energy

<table>
<thead>
<tr>
<th>Year</th>
<th>Lower Estimate Available LFG @ 50% CH₄ scfm</th>
<th>Thermal Energy mmBTU/hr</th>
<th>Thermal Energy kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>372</td>
<td>11.3</td>
<td>3,307</td>
</tr>
<tr>
<td>2009</td>
<td>418</td>
<td>12.7</td>
<td>3,715</td>
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<tr>
<td>2010</td>
<td>462</td>
<td>14</td>
<td>4,114</td>
</tr>
<tr>
<td>2011</td>
<td>429</td>
<td>13</td>
<td>3,816</td>
</tr>
<tr>
<td>2012</td>
<td>402</td>
<td>12.2</td>
<td>3,578</td>
</tr>
<tr>
<td>2013</td>
<td>382</td>
<td>11.6</td>
<td>3,394</td>
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<tr>
<td>2014</td>
<td>367</td>
<td>11.1</td>
<td>3,263</td>
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<tr>
<td>2015</td>
<td>357</td>
<td>10.8</td>
<td>3,178</td>
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<tr>
<td>2016</td>
<td>353</td>
<td>10.7</td>
<td>3,139</td>
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<td>2017</td>
<td>353</td>
<td>10.7</td>
<td>3,141</td>
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<td>2018</td>
<td>358</td>
<td>10.9</td>
<td>3,183</td>
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<tr>
<td>2019</td>
<td>367</td>
<td>11.1</td>
<td>3,262</td>
</tr>
<tr>
<td>2020</td>
<td>380</td>
<td>11.5</td>
<td>3,376</td>
</tr>
<tr>
<td>2021</td>
<td>396</td>
<td>12</td>
<td>3,524</td>
</tr>
<tr>
<td>2022</td>
<td>416</td>
<td>12.6</td>
<td>3,704</td>
</tr>
<tr>
<td>2023</td>
<td>440</td>
<td>13.4</td>
<td>3,915</td>
</tr>
<tr>
<td>2024</td>
<td>437</td>
<td>13.3</td>
<td>3,889</td>
</tr>
<tr>
<td>2025</td>
<td>396</td>
<td>12</td>
<td>3,519</td>
</tr>
<tr>
<td>2026</td>
<td>358</td>
<td>10.9</td>
<td>3,184</td>
</tr>
<tr>
<td>2027</td>
<td>324</td>
<td>9.8</td>
<td>2,881</td>
</tr>
</tbody>
</table>

13. OPTIONS FOR UTILIZATION

A number of options exist for the utilization of landfill gas for heat and electricity generation. The methane content of landfill gas can also be separated from the other components and used to supplement natural gas supplies or, in certain circumstances, compressed for use as vehicle fuel.
In addition, because methane from solid waste disposal on land is one of the major sources of anthropogenic greenhouse gas emissions, its capture and oxidation to carbon dioxide results in an environmental benefit. This benefit may be measured and traded under a number of different emission reduction trading schemes worldwide.

13.1. Thermal Energy

Landfill gas has been used in a number of industrial or agricultural processes that require thermal energy input. In circumstances where there is a direct use for heat within a reasonable distance from the landfill site, a potential exists for low cost utilization of the landfill gas. Landfill gas has been used for projects including the firing of brick kilns or other ceramic manufacture, heating of greenhouses and other industrial spaces. It should be noted that the combustion products of landfill gas, without pretreatment, may contain compounds that are hazardous to health including dioxins and furans. Therefore, direct use of landfill gas in agricultural processes in a manner where the combustion device exhaust gas contacts the plants must be carefully controlled. However, using a boiler or other method of heat exchange to provide heat to a greenhouse and exhausting the gas to the outside atmosphere where it does not contact the plants in the greenhouse can avoid such health concerns.

As the waste incineration plant scheduled to commence operation in 2010 is located only 500 m away from the landfill, it may be economically feasible to transmit the landfill gas to the incineration plant and use it in the incineration process, which in turn would generate heat or electricity that can be sold to a local energy company. Another option is to use the landfill gas as fuel or electricity at a medical waste incineration plant located 3 km away from the landfill.

The landfill gas could also be processed and injected into a natural gas pipeline located less than 100 m away from the landfill boundary. However, extensive gas purification (to remove CO₂ and other constituents and create a stream that is predominantly methane) is often required prior to injecting landfill gas into a natural gas pipeline, and this level of purification is relatively expensive. It may also be feasible to attract certain industries to establish industrial facilities or a greenhouse near the landfill, such that they are able to utilize the landfill gas supply as a low cost energy source for heat or power in various industrial processes.

13.2. Electrical Energy

Electrical energy can be produced with a variety of technologies. The majority of landfill gas to energy projects uses standard reciprocating internal combustion engine-generator sets of typically 800 kilowatt (kW) capacity or greater, while very large projects have used conventional gas turbines producing from 3 MW to upwards of 10 MW. Small reciprocating engine-generator sets can also be used for smaller project sized between 100 kW and 1 MW.

Recently developed microturbine technology, typically in the 30 kW to 750 kW range, has also been used on a number of smaller landfill gas projects because the new technology offers low emissions and low maintenance costs. Microturbines, however, tend to operate at lower thermal efficiencies than reciprocating engines.

From the predicted gas availability at the Weihai City Landfill, it appears there will be sufficient gas available to operate a standard reciprocating engine-generator. On the other hand, it may be advantageous to install a smaller generator or microturbine, which could be used either to supply power for on site consumption or to the local grid, in combination with direct use of some of the landfill gas.
14. EMISSIONS TRADING

It is possible to account for, and transfer, the reduction in greenhouse gas (GHG) emissions (i.e., GHG credits) resulting from activities that reduce or capture any of the six main greenhouse gases. Because methane from solid waste disposal on land is one of the major sources of anthropogenic greenhouse gas emissions, its capture and oxidation to carbon dioxide results in an environmental benefit. This benefit may be measured and traded under a number of different emission reduction trading schemes worldwide.

In order to qualify for trading of emission reductions, normally a project must be able to prove that there is no requirement under law, or mandated by waste disposal licenses or other regulations, to control the emission of the particular greenhouse gas relating to the project. This used to be relatively straightforward for landfills in China, where landfills were not required to control the emission of methane-containing landfill gas. However, with the promulgation of “Standard for Pollution Control on the Landfill Site of Municipal Solid Waste” (GB16889-2008, effective July 1, 2008), the situation may have entered a grey zone where subjective interpretation of the regulation and its implementation is important. On the one hand, the new standard requires MSW landfills with design capacity greater than 2.5 million tons and waste thickness greater than 20m (which includes the Weihai City Landfill) to construct a landfill gas utilization facility or flare(s) to handle the methane-containing landfill gas. On the other hand, it is not clear whether the new standard is applicable to all existing landfills and, if so, the deadline for compliance; furthermore, even if the new standard does apply to existing landfills, it is possible to argue that some (if not all) of the direct methane reduction (via flaring or utilization) should qualify for GHG credits. Ultimately, this would be a determination that will be made by the relevant governing regulating body.

Assuming the project is qualified for trading of emission reductions, the calculation of emission reductions is defined by methodologies relating to the particular trading mechanisms.

As part of all methodologies, it must be proven that normal business practice does not alter the emissions of greenhouse gases. Examination of the Weihai City Landfill indicates that, although not required by law, the site is already operating an enclosed flare that destroys some of the methane generated at the site. Therefore, in assessing the amount of emission reductions available from the site, there is a need to apply an adjustment factor. Based on the fact that the design capacity of the flare is sufficient to handle all of the landfill gas expected to be recovered at the site, it is reasonable to assume that normal practice at this site would be the destruction of all recoverable methane and that an adjustment factor of 100% would be appropriate. However, since part of the landfill has only passive vents at the present, it may be possible to argue that the baseline for that part of the landfill is no control of methane emissions, and that conversion of the passive vents to active wells should qualify for emission reduction credits. In that case, the adjustment factor would be less than 100%. For this study, however, the adjustment factor is assumed to be 100%; this is a conservative and realistic assumption for the purpose of estimating financial feasibility.

The following Equation 3 estimates the number of emission reductions available in each year from the Weihai City Landfill as a result of direct methane reduction.

**Equation 3 - Available Emission Reductions**

\[ T_{\text{Avail \, CO}_2 \text{eq.}} = \left(1 - AF\right) \times \%_{\text{vol}} \times 21 \times Q_{\text{Avail}} \times \rho_{\text{CH}_4} \]
Where:

- $T_{\text{AvailCO2eq.}}$: Total emission reductions available in Tonnes of Carbon Dioxide Equivalent (tCO2e)
- $\%_{\text{vol}}$: Volumetric percentage of methane in landfill gas
- $Q_{\text{Avail}}$: Total quantity of landfill gas available
- $AF$: Adjustment Factor (100% in this case)
- $\rho_{\text{CH4}}$: Density of Methane = 0.0007168 Tonnes / cubic meter

While flaring is the normal method for thermal oxidation of landfill gas, any process which prevents the emission of methane to the atmosphere also qualifies for tradable emission reductions. The carbon dioxide created by the thermal oxidation of methane is considered to be "short cycle" and a product of the normal carbon cycle, and therefore does not need to be accounted for under the current methodologies.

If electrical energy production is also included, and that power is either exported to the local distribution network or used to displace other usage of electricity, it is possible to gain additional emission reductions as a result of the displacement of fossil fuel use. To calculate the number of emission reductions available in each year from the export of electricity, the following equation is used:

**Equation 4 - Emission Reductions from Fossil Fuel Offset due to Generation of Electricity**

$$T_{\text{CO2eq.}} = EF_{\text{grid}} \times MWh_{\text{exported}}$$

Where:

- $T_{\text{CO2eq.}}$: Total emission reduction in Tonnes of Carbon Dioxide Equivalent (tCO2e)
- $EF_{\text{grid}}$: Grid emission factor (0.9928 tCO2/MWh for the Huabei Grid of China [4], which includes Shandong Province)
- $MWh_{\text{exported}}$: Total number of mega-watt hours exported to the grid.

Instead of electricity generation, the landfill gas could also be utilized in a direct use scheme at a facility on or close to the site (such as the planned waste incineration plant). In this case, it is also possible to gain additional emission reductions as a result of the displacement of fossil fuel use. Assuming the fossil fuel displaced is natural gas, the following equation can be used to calculate the number of emission reductions available in each year from direct use:

**Equation 5 - Emission Reductions from Fossil Fuel Offset due to Direct Use**

$$T_{\text{CO2eq.}} = EF_{\text{fossil fuel}} \times \%_{\text{vol}} \times \frac{H_{\text{methane}}}{H_{\text{natural gas}}} \times Q_{\text{direct use}}$$

Where:

- $T_{\text{CO2eq.}}$: Total emission reduction in Tonnes of Carbon Dioxide Equivalent (tCO2e)
- $EF_{\text{fossil fuel}}$: Emission factor (54.71 tCO2/mcf for natural gas)
- $\%_{\text{vol}}$: Volumetric percentage of methane in landfill gas
- $H_{\text{methane}}$: Heat content of methane (1012 Btu/ cf)
- $H_{\text{natural gas}}$: Heat content of natural gas (1050 Btu/ cf)
- $Q_{\text{direct use}}$: Total volume of landfill gas utilized in direct use (in million cubic feet, or mcf).
On the basis of the calculated availability of landfill gas at the Weihai City Landfill, and assuming that all the methane is used for energy generation (electricity generation or direct use) and/or flaring, the possible amount of emission reductions generated in the next 20 years is shown in Table 7. Emission reductions produced by electricity generation or direct use result from the displacement of the use of fossil fuels and are therefore additional to flaring activities. The estimates shown in Table 6 are based on the assumption that an enclosed flare is used to ensure a high combustion efficiency (>99%), and that the efficiency of the electricity generator is approximately 38%.

Table 7 - Estimated Available Emission Reductions

<table>
<thead>
<tr>
<th>Year</th>
<th>CO₂ Equivalent Tonnes from Flaring Activities</th>
<th>Additional CO₂ Equivalent Tonnes from Electricity Generation*</th>
<th>Additional CO₂ Equivalent Tonnes from Direct Use*</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>0</td>
<td>10,928</td>
<td>5,151</td>
</tr>
<tr>
<td>2009</td>
<td>0</td>
<td>12,278</td>
<td>5,788</td>
</tr>
<tr>
<td>2010</td>
<td>0</td>
<td>13,596</td>
<td>6,409</td>
</tr>
<tr>
<td>2011</td>
<td>0</td>
<td>12,611</td>
<td>5,945</td>
</tr>
<tr>
<td>2012</td>
<td>0</td>
<td>11,823</td>
<td>5,573</td>
</tr>
<tr>
<td>2013</td>
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<td>11,218</td>
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<td>2014</td>
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<td>5,083</td>
</tr>
<tr>
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</tr>
<tr>
<td>2018</td>
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<td>4,959</td>
</tr>
<tr>
<td>2019</td>
<td>0</td>
<td>10,780</td>
<td>5,082</td>
</tr>
<tr>
<td>2020</td>
<td>0</td>
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</tr>
<tr>
<td>2021</td>
<td>0</td>
<td>11,647</td>
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<tr>
<td>2022</td>
<td>0</td>
<td>12,242</td>
<td>5,771</td>
</tr>
<tr>
<td>2023</td>
<td>0</td>
<td>12,940</td>
<td>6,100</td>
</tr>
<tr>
<td>2024</td>
<td>0</td>
<td>12,853</td>
<td>6,059</td>
</tr>
<tr>
<td>2025</td>
<td>0</td>
<td>11,630</td>
<td>5,482</td>
</tr>
<tr>
<td>2026</td>
<td>0</td>
<td>10,523</td>
<td>4,961</td>
</tr>
<tr>
<td>2027</td>
<td>0</td>
<td>9,522</td>
<td>4,489</td>
</tr>
</tbody>
</table>

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

It should be noted that the quantity of emission reductions that will be realized will 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.
15. OUTLINE SPECIFICATION OF A GAS EXTRACTION SYSTEM

Although there is an existing active gas collection system at the Weihai City Landfill, it covers only 40% of the landfilled area. A comprehensive gas extraction system with optimized areal coverage and collection efficiency will be required to maximize gas recovery; the system can be constructed from scratch, or it can be an expansion of the existing system. The following general description outlines the equipment and operations required for this purpose.

Landfill gas will be extracted from the site through a number of vertical and/or horizontal gas wells that are either drilled into the waste mass or installed during waste placement. The technology used for the installation of gas wells will vary depending on the location (it may also be possible to use the existing extraction wells or passive vents as collection or temporary collection elements). Permanent gas wells are normally drilled, using heavy duty drilling equipment, into the waste mass, to within 2 m of the base of the site. The gas wells are typically constructed with plastic pipe, which is perforated below the surface. The top section of the well casing is usually solid (non-perforated) and is sealed with hydrated sodium bentonite. In locations that are not suitable for permanent installation, for example in areas where further waste deposits are planned, temporary gas wells can be installed. The temporary gas wells could consist of either vertical steel or plastic perforated tubes, or in some circumstances a horizontal perforated plastic pipe can be laid within the waste.

It is important that all wells have a solid (non-perforated) section from the surface to a depth of several meters and that this is sealed to prevent air ingress. However, the length of the solid section may have to be reduced in areas with high leachate levels. Horizontal collection pipes can be placed under the advancing waste front. These consist of heavy duty perforated pipe that will emerge from the waste at the sides of the site.

Each gas well will be equipped with a flow control valve and with monitoring facilities to collect gas samples and measure flow rates and vacuum. The gas wells will be connected to a non-perforated plastic pipe network through facilities that allow the operator to control the flow of landfill gas and record primary constituents of the gas as well as pressure and temperature at each location.

Dewatering facilities are located in the pipe network to allow liquid condensates to drain from the piping via a barometric trap (with liquid seal), and either re-injected into the waste mass or pumped to collection points. Additional removal of moisture from the landfill gas occurs at a knock-out vessel located prior to entry to the flare facility or utilization equipment.

Landfill gas will be drawn out of the collection pipe network under vacuum created by a centrifugal gas blower or exhauster. This blower / exhauster is used to supply vacuum and pressurize the landfill gas prior to combustion in the flare stack or delivery to utilization equipment.

Two different types of flare stacks exist for thermal oxidation of landfill gas. Larger installations will typically utilize enclosed flares, where the landfill gas is combusted in a temperature controlled chamber. These flares have very high destruction efficiency for oxidation of methane and also destruction of the hazardous air pollutants (HAPs) found in landfill gas. Simpler, "elevated" or "candle stick" flares burn gas in an open flame and do not achieve combustion efficiencies matching enclosed models, but they require considerably lower capital costs. To maximize the destruction of methane, it is necessary to use an enclosed flare, offering around 99% destruction efficiency (compared to a candle stick flare, which is assumed by some IPCC emission reduction methodologies to have an efficiency of
around 50%). At the Weihai City Landfill, an enclosed flare was observed in operation, albeit at a relatively low flow rate.

For the purposes of this study, one gas well was assumed to be required per acre of the landfill. This assumption should be confirmed through the use of a gas pump test. Some of the existing extraction wells and passive vents could become part of the final gas extraction system, assuming they are not damaged during waste and/or cover placement and their construction meets the requirement of permanent wells. Although the existing active gas collection system covers approximately 40% of the landfilled area, additional wells will need to be installed between the existing wells to optimize gas control since the spacing between the existing wells appeared to be too large. As more waste placement is envisaged on top of the current waste platform, it is necessary to protect any gas vents / wells installed prior to the completion of this operation. One way to achieve this is through careful placement of waste around the wells and extension of the well tubes to the new surface. Alternatively, the existing wells can be treated as temporary, to be abandoned and replaced by permanent wells installed when the landfill reaches final grades.

In order to maximize gas collection efficiency, gas collection system components should be installed during the waste placement operation. The option to use horizontal gas collectors, at least for temporary collection purposes, should be considered. Horizontal gas collection pipes, which typically consist of plastic perforated pipe, could be installed in trenches constructed at the top of previously placed waste. Caution should be taken to cover the horizontal collectors with at least 4 to 6m of waste to minimize air intrusion, while limiting the depth to avoid flooding.

16. FINANCE MODEL

A preliminary financial assessment of alternative LFG energy projects at the Weihai City Landfill has been performed using the U.S. EPA Landfill Gas Energy Cost Model (LFGcost, Version 1.4, August 2006). LFGcost is a software tool for performing preliminary economic analyses of prospective landfill energy recovery projects.

The costs 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.

Furthermore, LFGcost was developed using cost and other financial data specific to the United States. Although the model allows the user to choose between suggested default data and user data for a number of optional input parameters (such as General Inflation Rate) that facilitate the customization of LFGcost for other countries, there are many underlying assumptions (such as cost of well drilling) based on US cost data that are embedded in the model. No changes to the embedded parameters in LFGcost were made in this study except for the Grid Emission Factor, for which the value of 0.9928 tCO₂/MWh was adopted for the Huabei Grid of China.
As indicated previously, \textit{LFGcost} was developed using cost data specific to the United States. Since labor and material costs in China are typically lower than the corresponding costs in the US, costs estimated by \textit{LFGcost} (especially O&M costs, and to a lesser extent capital costs) should be adjusted downwards for China. \textit{LFGcost} allows for such an adjustment via an optional user input called Cost Uncertainty Factor. For this assessment study, the Cost Uncertainty Factor was assumed to be zero (i.e., no adjustment) to be conservative.

Values of some of the key optional input parameters selected for use in this assessment for the Weihai City Landfill are presented in Table 8. Unless stated otherwise, all “$”s in this report refer to US dollars.

<table>
<thead>
<tr>
<th>Key Parameter</th>
<th>Selected Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Lifetime</td>
<td>15 years</td>
</tr>
<tr>
<td>Loan Lifetime</td>
<td>10 years</td>
</tr>
<tr>
<td>Interest Rate</td>
<td>8%</td>
</tr>
<tr>
<td>General Inflation Rate</td>
<td>4%</td>
</tr>
<tr>
<td>Equipment Inflation Rate</td>
<td>3%</td>
</tr>
<tr>
<td>Marginal Tax Rate</td>
<td>25%</td>
</tr>
<tr>
<td>Discount Rate</td>
<td>10%</td>
</tr>
<tr>
<td>Down payment</td>
<td>20%</td>
</tr>
<tr>
<td>Renewable electricity credit *</td>
<td>$0.036/kWh</td>
</tr>
<tr>
<td>Initial year LFG product price</td>
<td>$6.79/mmBtu</td>
</tr>
<tr>
<td>Initial year electricity product price</td>
<td>$0.0408/kWh</td>
</tr>
<tr>
<td>Annual product price escalation rate</td>
<td>7%</td>
</tr>
<tr>
<td>Electricity purchase price</td>
<td>$0.113/kWh</td>
</tr>
<tr>
<td>Annual electricity purchase price escalation rate</td>
<td>11.5%</td>
</tr>
</tbody>
</table>

* Stipulated by the PRC Law on Renewable Energies (2005).

In addition, certain key assumptions embedded in \textit{LFGcost} are listed in Table 9:

<table>
<thead>
<tr>
<th>Item</th>
<th>Assumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equipment Depreciation</td>
<td>100% over project lifetime (15 years in this case)</td>
</tr>
<tr>
<td>Gross Capacity Factor</td>
<td>93% for Standard Reciprocating Engine-Generator</td>
</tr>
<tr>
<td></td>
<td>90% for Direct Use</td>
</tr>
<tr>
<td>Parasitic Loss Efficiency</td>
<td>92% for Standard Reciprocating Engine-Generator</td>
</tr>
</tbody>
</table>
Since there is an active gas collection system already in part of the landfill, only the capital cost for expanding the existing wellfield to a full active gas collection system was included in the LFGcost analyses; the capital cost for an enclosed flare was not included in the analyses, because an enclosed flare of sufficient size is already operating at the site. However, the O&M costs for the full gas collection system and the enclosed flare are included in the analyses.

Based on the moderate amount of landfill gas estimated to be available at the Weihai City Landfill, two types of energy projects (namely electricity generation with standard reciprocating engine and direct use) were evaluated in this assessment. For the electricity generation project, the project components were sized to handle the average landfill gas flow rate estimated over the project lifetime; whereas for the direct use project, the maximum estimated flow rate was used to size the project components.

For each type of energy project, a number of financial model scenarios have been run. Variations of the following two parameters have been used to develop the financial model scenarios:

1. Greenhouse Gas Reduction Credit (Emission Reductions) Price – Emission reductions that have been certified can be traded as Greenhouse Gas Reduction Credits in various carbon and emission markets. The price is market-driven, however. For this assessment study, the prices of $5, $15 and $25 per tCO$_2$e were used to evaluate the effect of price variation on the financial feasibility of the energy project.

2. The period of time for which emission reduction credits are available depends on the trading scheme, and one current program provides credits only through 2012. Although there are indications that the crediting period will be extended, trading of emission reductions beyond 2012 carries an uncertain amount of risk. For this assessment study, two scenarios related to the crediting period are evaluated: one ending in 2012 and the other extending throughout the project lifetime (i.e., ending in 2024 or beyond). [Since LFGcost was developed based on the assumption that revenue from sale of Greenhouse Gas Credits will be available throughout the project lifetime, a project-specific modification to LFGcost was made to allow a shortening of the crediting period.]

Variation of a third parameter, eligibility of Direct Methane Reduction for GHG credits, could have been evaluated. As discussed in Section 14, it is not clear if all direct methane reductions at landfills in China via control of landfill gas still qualify for greenhouse gas (GHG) credits due to the recently promulgated “Standard for Pollution Control on the Landfill Site of Municipal Solid Waste” (GB16889 – 2008). As such, two scenarios related to this parameter could have been evaluated: one assuming all direct methane reductions qualify for GHG credits, and the other assuming none of the direct methane reductions qualify. However, due to the fact that there is an existing and operating enclosed flare that can handle all landfill gas expected to be recovered at the site, it is likely that no direct methane reduction would qualify for greenhouse gas credits at this site. Therefore, variation of this parameter was not evaluated in the financial model. It was assumed that the landfill would not qualify for direct methane reduction credits, but that it could qualify for credits for CO$_2$ reduction from displacement of fossil fuel combustion.

An example of the output from LFGcost is presented in Appendix I; a summary of the LFGcost results is presented in Tables 10 and 11. In all cases, the Internal Rate of Return and Net Present Value (based on a 10% discount rate, including return of initial investment) have been modeled.
Table 10 – Summary of LFGcost Results (Crediting Period ending in 2012)

<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>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>Standard Reciprocating Engine-Generator 1007kW</td>
<td>$2,682,081</td>
<td>$455,091</td>
<td>IRR -1%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>NPV -$903,965</td>
</tr>
<tr>
<td>Direct Use</td>
<td>$1,125,389</td>
<td>$369,655</td>
<td>IRR 62%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>NPV $1,756,943</td>
</tr>
</tbody>
</table>

Table 11 – Summary of LFGcost Results (Crediting Period ending in 2024 or beyond)

<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>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>Standard Reciprocating Engine-Generator 1007kW</td>
<td>$2,682,081</td>
<td>$455,091</td>
<td>IRR 1%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>NPV -$744,070</td>
</tr>
<tr>
<td>Direct Use</td>
<td>$1,125,389</td>
<td>$369,655</td>
<td>IRR 63%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>NPV $1,842,540</td>
</tr>
</tbody>
</table>

The above LFGcost results indicate that for scenarios corresponding to crediting period ending in 2012, an electricity generation project using standard reciprocating engines is not feasible for the three assumed emission reductions prices.

With the crediting period ending in 2012, a direct use project is highly feasible for all three assumed emission reductions prices.

For scenarios corresponding to crediting period ending in 2024 or beyond, an electricity generation project using standard reciprocating engines is not feasible when the price of emission reductions is $5/tCO2e or less, but it would be marginally feasible if the price is $15/tCO2e, and moderately feasible if the price is $25/tCO2.

With the crediting period ending in 2024 or beyond, a direct use project is highly feasible for all three assumed emission reductions prices.

It should be noted that the above evaluation assumed that the regulation stipulating the provision of $0.036/kWh renewable energy credit to the producer of renewable energies (The Law on Renewable
Energies, 2005) will remain in effect throughout the project lifetime. Since the revenue from renewable energy credit constitutes a substantial portion of the total revenues, any changes to the Law on Renewable Energies would likely have a significant impact on the project’s financial feasibility.
17. CONCLUSIONS

The analysis documented in this assessment report indicates that the Weihai City Landfill produces a moderate amount of LFG, and that a landfill gas utilization project could be technically and financially feasible. Consideration of current energy costs and emission reduction pricing, over the crediting periods appears to favor the direct use option for an energy recovery project.

Both the financial feasibility and the type of energy project that may prove to be feasible would depend to a large extent on the crediting period during which emission reductions are valid, the price of emission reductions, and whether direct methane reductions are eligible for greenhouse gas credits under the newly promulgated National Standard on pollution control at landfills. Financial feasibility is similarly related to the implementation of proper solid waste management practices required to achieve a reasonable level of LFG production and improved gas collection efficiencies.

To implement such a project, a viable end user within a reasonable distance from the site should be identified. During the recent site visit, two potential options for the use of the landfill gas was identified; as fuel for the nearby planned waste incineration plant or for the medical waste incineration plant 3km away from the site. Other industrial processes could potentially be sited near, or on the landfill site, to utilize LFG fueled heat or power.
REFERENCES


2. The United States Environmental Protection Agency’s Landfill Methane Outreach Program (LMOP) at the Third International Methane and Nitrous Oxide Mitigation Conference, 17th to 21st November 2003, in Beijing, China.


APPENDIX I

EXAMPLE OF *LFGCOST* OUTPUT
U.S. EPA Landfill Methane Outreach Program

Landfill Gas Energy Cost Model
LFGcost, Version 1.4
Summary Report

Landfill Name or Identifier:  Weihai City Landfill, Shandong Province
LFGE Project Type:  Standard Reciprocating Engine-Generator Set
Date:  Monday, September 29, 2008

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: 2010
Project End Year: 2024
Project Type: Standard Reciprocating Engine-Generator Set

Financial Results:
- Net Present Value: ($658,016) (at year of construction)
- Internal Rate of Return: 3%
- Net Present Value Payback (yrs): None (years after operation begins)
- Capital Costs: $3,157,845
- O&M Costs: $454,897 (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): 1,618
(MMTCO₂E): 6.52E-01

Average Annual

(million ft³ methane/yr): 108
(MMTCO₂E/yr): 4.35E-02

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

Lifetime (MMTCO₂E): 1.19E-01
Average Annual (MMTCO₂E/yr): 7.92E-03

Landfill Characteristics

Open Year: 2000
Closure Year: 2024
Waste-In-Place at Closure (tons): 1,663,999
Average Waste Acceptance (tons/yr): 69,333
Average Depth of Landfill Waste (ft): 45
Area of LFG Wellfield to Supply Project (acres): 80

Landfill Gas Generation, Collection, and Utilization

Modeling Parameters for First-Order Decay Equation:

- Methane Generation Rate, k (1/yr): 0.100
- Methane Generation Capacity, L₀ (ft³/ton): 2,884
- Methane Content of LFG: 50%

Generated During Project Lifetime (ft³/min):

Minimum: 567
Annual Average: 631
Maximum: 743

Collected During Project Lifetime (ft³/min):

Minimum: 368
Annual Average: 410
Maximum: 483

Project Size: Average

Design Flow Rate for Project (ft³/min): 410

Utilized by Project (ft³/min):
Annual Average: 367

LFG Collection Efficiency: 65%

Financial Assumptions

Loan Lifetime (years): 10
Interest Rate: 8.0%
General Inflation Rate: 4.0% (applied to O&M costs)
Equipment Inflation Rate: 3.0%
Marginal Tax Rate: 25.0%
Discount Rate: 10.0%
Down Payment: 20.0%
Collection and Flaring Costs: Included

Electricity Production and Sales Summary

Total Generation Capacity (kW): 1,108
Average Generation (million kWh/yr): 7.977 (during the life of the project)
Initial Year Electricity Price ($/kWh): 0.0408
Price to Achieve Financial Goals ($/kWh): 0.045 (determined by Financial Goals Calculator results)
GAS ANALYZER CALIBRATION REPORT

Calibration Date: 21-Jun-08

DETAILS OF EQUIPMENT TO BE CALIBRATED

Equipment: CES-Landtec Portable Landfill Gas Analyzer
Model: GEM 2000
Range: CH₄: 0% - 100% v/v
      CO₂: 0% - 60% v/v
      O₂: 0% - 21% v/v
Procedures: Check against calibration gases on known concentrations. Adjust if necessary.

CALIBRATION GASES USED

<table>
<thead>
<tr>
<th>Cylinder No.1</th>
<th>Cylinder No.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Certificate No.: T07/04172</td>
<td>Certificate No.: T08/01614</td>
</tr>
<tr>
<td>Cylinder No.: P6176</td>
<td>Cylinder No.: SG03133</td>
</tr>
<tr>
<td>Composition:</td>
<td>Composition:</td>
</tr>
<tr>
<td>15.4% N₂</td>
<td>95.1% N₂</td>
</tr>
<tr>
<td>35.2% CO₂</td>
<td>0.0% CO₂</td>
</tr>
<tr>
<td>49.4% CH₄</td>
<td>0.0% CH₄</td>
</tr>
<tr>
<td>0.0% O₂</td>
<td>4.9% O₂</td>
</tr>
</tbody>
</table>

CALIBRATION RESULT(S)

<table>
<thead>
<tr>
<th>Cylinder No.1</th>
<th>Cylinder No.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH₄</td>
<td>Before</td>
</tr>
<tr>
<td>49.8%</td>
<td>49.4%</td>
</tr>
<tr>
<td>CO₂</td>
<td>35.4%</td>
</tr>
<tr>
<td>O₂</td>
<td>0.0%</td>
</tr>
<tr>
<td>Balance gas</td>
<td>14.8%</td>
</tr>
</tbody>
</table>

Reported by: K.Y. Lam
Checked by: Kenny Chak

Distribution: (1) Site file; (2) HKLRG (by hand only)
APPENDIX III

AERIAL PHOTO
Aerial View of Weihai City Landfill

Source: Google™ Maps (http://maps.google.com)
APPENDIX IV

SELECTED PHOTOS
Photo 1: Panoramic View of Waste Dam (Left) and Leachate Holding Lagoon (Right)

Photo 2: Panoramic View of Waste Platform and Tipping Area
Photo 3: General Layout Drawing of the Weihai City Landfill

Photo 4: Landfill Entrance
Photo 5: Landfill Weighbridge

Photo 6: A Typical Gas Collection Wellhead
Photo 7: A Typical Passive Gas Vent

Photo 8: Measurement at Vent Pipe with GEM-2000 Portable Unit
Photo 9: Bulldozer in Operation in Tipping Area

Photo 10: Stormwater Drainage Channel along the Perimeter of Landfill
Photo 11: View of Recently Disposed Waste

Photo 12: Landfill Gas Collection Manifold
Photo 13: Enclosed Landfill Gas Flare

Photo 14: The Gas Flaring System Control Panel
Photo 15: On-site Gas Analyzer