Assessment of Landfill Gas Potential:
Chengdu City Landfill
FINAL

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EXECUTIVE SUMMARY

The Chengdu City landfill is owned and operated by the Chengdu City Solid Waste Sanitary Treatment Centre (CSWSTC). Chengdu City Landfill is located in Chang’an Village within the Luodai Township, approximately 30 km east of the city center.

Site operation began in September 1993 and all municipal solid waste from Chengdu City was placed in the Chengdu City landfill. Waste intake for the first full year of operation (1994) was only 637,940 tonnes (or 1,750 tonnes per day). By year 2008, daily waste intake has reached 4,900 tonnes per day (equivalent to 1,788,500 tonnes per year). Data provided by the site indicated that the total waste in place has reached 15,292,884 tonnes by the end of 2008. Based on information provided by the site, the two existing phases of the landfill will likely be full by the end of 2011; a future extension of the landfill (Phase III) was reportedly being planned but no details were provided.

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 Chengdu City Landfill’s potential to generate methane. Analysis of the data provided by the Chengdu City Solid Waste Sanitary Treatment Centre (CSWSTC) indicates that the site could be currently emitting between 3,655 and 5,921 standard cubic feet per minute (scfm) (6,214 and 10,066 m³/hr) of landfill gas, containing approximately 50% methane. This rate could reach an approximate peak of between 4,249 and 6,470 scfm (7,223 and 10,999 m³/hr) in 2012. However, due to the current construction and operational techniques employed at the site, not all of this landfill gas will be available for utilization. We estimate that the amount of landfill gas that could currently be collected for beneficial use is 2,375 scfm (4,036 m³/hr) and will peak at 2,762 scfm (4,693 m³/hr) in 2012. This is intended to be a slightly conservative, yet realistic estimate of recoverable gas.

The introduction and implementation of proper solid waste management practices will improve gas collection efficiency. Internationally accepted solid waste management practices that promote landfill gas generation and collection typically include 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 subsurface combustion.

With a significant and relatively steady quantity of landfill gas available from the landfill and the presence of potential end users for the gas or electricity generated with the gas, either on or near the site (e.g., existing on-site facilities including the leachate treatment plant, office buildings and maintenance depot, and the planned medical waste treatment plant adjacent to the site), there is a good opportunity for development of landfill gas to energy projects using the Chengdu City Landfill’s gas. Both direct use and electricity generation projects appear to be technically and financially feasible.

The economic outlook of the project is enhanced by the ability to take advantage of renewable incentives and greenhouse gas (carbon) reduction incentives. As the landfill design capacity is greater than 2.5 million tonnes, the minimum capacity above which a landfill would be required to install methane utilization facility or flares under the “Standard for Pollution Control on the Landfill Site of Municipal Solid Waste” (GB16889-2008, effective July 1, 2008), an energy project at the Chengdu City Landfill would likely not qualify for greenhouse gas credits from direct methane emission reductions. Even if the landfill qualifies for greenhouse gas credits from direct methane emission reductions, it is likely that only a fraction of the direct methane emission reductions could earn
greenhouse gas credits due to the existence of a landfill gas collection and flaring system that covers part of the landfill (even though the system has not been operating since early 2009). For this study, it is assumed that the landfill does not qualify for greenhouse gas credits from direct methane emission reductions. However, the landfill would still qualify for credits for CO₂ reduction from displacement of fossil fuel combustion. The financial 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. The Chengdu City Landfill site was visited to collect information on landfill design, waste volume, waste composition and gas composition, and to make observations to assess its gas generation and recovery potential. 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 and presents our observations and findings on the Chengdu City Landfill in Chengdu City, Sichuan Province, China. This report includes a brief assessment of the gas production and recovery 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 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 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.
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.

Although there is a gas collection and flaring system that covers part of the Chengdu City landfill, operation of the system has been suspended since early 2009 due to poor gas yield, probably as a result of high leachate levels. Also, the gas extraction wells and laterals and most of the header pipe are buried under the waste. Although it might be possible to incorporate the existing blower and/or flares into a future system, it is envisaged that a collection system with new wells, utilization equipment, and additional blowers and flares would be required to extract gas from the entire site for future flaring and utilization. The capital and O&M costs, return on investment and net present value resulting from installing such a system at the Chengdu 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 the Chengdu 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, 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 greenhouse gas. 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 greenhouse gas emissions.

Methane is a more potent greenhouse gas 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 greenhouse gas emissions. Additional benefits beyond greenhouse gas 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 to 500 Btu per cubic feet (or 14.9 to 18.6 MJ per cubic meter), 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 of the medium-BTU gas for heating/fuel for boilers, kilns, or furnaces; 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 use projects at Chengdu 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 performed on 26 March 2009. Prior to the site visit, the Chengdu Academy of Urban Environmental Management (CAUEM), which has a close relationship with the site management, the Chengdu City Solid Waste Sanitary Treatment Centre (CSWSTC), was requested to provide information on the waste inputs, engineering details, and environmental conditions of the site via a questionnaire. Data provided by the operator 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 Chengdu City Landfill.

4.1. Site Location and Operation

Chengdu City Landfill is located in Chang’an Village within the Luodai Township, approximately 30 km east of the city center. It is west and uphill of the famous old town of Luodai, the largest Hakka village in China and a favorite tourist attraction in the vicinity of Chengdu City.

The site is located in a remote valley. No other immediate domestic or industrial neighborhoods were observed during the site visit. High voltage transmission lines, originating from an electrical substation downhill from the site, were observed to run along the southern site boundary.

The design capacity is 32.09 million cubic meters with an overall site footprint of 104 hectares (Ha) and a waste footprint of 35 Ha. The existing landfill consists of two phases: Phase I with a design capacity of 11.35 million cubic meters, and Phase II with a design capacity of 20.74 million cubic meters (although some of the phase II area has been used for sludge ponds so the actual capacity available for waste placement is smaller). A future extension of the landfill (Phase III) was reportedly being planned but no details were provided.
The Chengdu City landfill is owned and operated by the Chengdu City Solid Waste Sanitary Treatment Centre (CSWSTC) and has close relationships with the Chengdu Academy of Urban Environmental Management (CAUEM).

4.2. Waste Inputs

Site operation began in September 1993 and all municipal solid waste from Chengdu City was placed in the Chengdu City landfill. Waste intake for the first full year of operation (1994) was only 637,940 tonnes (or 1,750 tonnes per day). By year 2008, daily waste intake has reached 4,900 tonnes per day (equivalent to 1,788,500 tonnes per year). Data provided by the site indicated that the total waste in place has reached 15,292,884 tonnes by the end of 2008.

A weighbridge was located by the site entrance and all trucks are weighed prior to entry. Daily summary tables of incoming trucks, including the district of origin, vehicle number and amount of waste were provided for review.

Reported waste input to the site from 1993 to 2008 is shown in Table 1.

<table>
<thead>
<tr>
<th>Year</th>
<th>Total Tonnes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1993 (Sep to Dec.)</td>
<td>20,671</td>
</tr>
<tr>
<td>1994</td>
<td>637,940</td>
</tr>
<tr>
<td>1995</td>
<td>710,128</td>
</tr>
<tr>
<td>1996</td>
<td>683,353</td>
</tr>
<tr>
<td>1997</td>
<td>796,020</td>
</tr>
<tr>
<td>1998</td>
<td>839,742</td>
</tr>
<tr>
<td>1999</td>
<td>891,953</td>
</tr>
<tr>
<td>2000</td>
<td>581,686</td>
</tr>
<tr>
<td>2001</td>
<td>657,914</td>
</tr>
<tr>
<td>2002</td>
<td>794,154</td>
</tr>
<tr>
<td>2003</td>
<td>1,176,472</td>
</tr>
<tr>
<td>2004</td>
<td>1,212,000</td>
</tr>
<tr>
<td>2005</td>
<td>1,343,320</td>
</tr>
<tr>
<td>2006</td>
<td>1,477,016</td>
</tr>
<tr>
<td>2007</td>
<td>1,618,515</td>
</tr>
<tr>
<td>2008</td>
<td>1,788,500</td>
</tr>
<tr>
<td>Total</td>
<td>15,292,884</td>
</tr>
</tbody>
</table>

To estimate the waste intake for 2009 and beyond, an annual growth rate of 4% is assumed. CSWSTC indicated an incineration plant in Luodai Township with a design capacity of 1,800 tpd began operating in 2008. It was also indicated that a second waste incineration plant in Chengdu City is under construction and would start operation in 2010, while a third one is anticipated to start operation by 2015. Site management also indicated that the three existing sludge ponds on site have taken up a substantial portion of the design capacity of Phase II, such that the existing landfill (Phases I and II)
would be full by the end of 2011. Based on the above information, waste intake from 2009 to 2011 were projected and provided in Table 2. It should be noted that the estimated waste input does not take the planned Phase III into consideration, as no details were available at the time of this study.

Table 2 - Estimated Waste Input 2009 - 2011

<table>
<thead>
<tr>
<th>Year</th>
<th>Total Tonnes</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>1,860,040</td>
</tr>
<tr>
<td>2010</td>
<td>1,277,442</td>
</tr>
<tr>
<td>2011</td>
<td>1,354,819</td>
</tr>
<tr>
<td>Total Future</td>
<td>4,492,301</td>
</tr>
<tr>
<td>TOTAL</td>
<td>19,785,185</td>
</tr>
</tbody>
</table>

5. WASTE COMPOSITION

Table 3 below presents the information provided by CSWSTC on the general composition of the waste in the Chengdu City Landfill. The reported composition is based on a waste characterization study performed by CAUEM on samples collected in May 2008.

Table 3 - Waste Composition

<table>
<thead>
<tr>
<th>Waste Category</th>
<th>Composition (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food Waste</td>
<td>43.3</td>
</tr>
<tr>
<td>Paper Waste</td>
<td>13.94</td>
</tr>
<tr>
<td>Textiles</td>
<td>3.02</td>
</tr>
<tr>
<td>Yard Waste</td>
<td>11.89</td>
</tr>
<tr>
<td>Metals and Large Appliances</td>
<td>0.42</td>
</tr>
<tr>
<td>Plastics / Rubber</td>
<td>9.52</td>
</tr>
<tr>
<td>Glass and ceramics</td>
<td>1.98</td>
</tr>
<tr>
<td>Wood</td>
<td>1.57</td>
</tr>
<tr>
<td>Other Inert Materials</td>
<td>14.37</td>
</tr>
<tr>
<td><strong>Sum</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

The percentage of organic waste (73.7%) is relatively high, with close to 55% of the waste being categorized as rapidly decaying. The average moisture content of the waste was reported to be at a fairly high value of 55.18%.

6. RECYCLING ACTIVITIES

The owner reported that recycling activities at the site have been terminated since 2004, upon the request of the local government. Observations during the site visit were consistent with this report.
7. LANDFILL FIRES

No landfill fires or signs of subsurface combustion were either reported or observed during the site visit.

8. SITE CONSTRUCTION

The general site conditions and engineering design features were examined during the site visit. Waste inflow and characteristic data were reviewed, operational practices observed, and gas quality monitoring data obtained (where available). The subsequent sections describe the pertinent features observed at the site.

8.1. General Observations

The site is located in a remote valley that slopes generally from southwest to northeast and is surrounded by hilly areas with dense vegetation.

At the time of the site visit, Phase I has already reached its design capacity and most of the waste in Phase I has been covered with an HDPE liner. Construction of Phase II, which entails waste placement on top of Phase I as well as downstream and northeast of Phase I, is currently ongoing. A waste dam at the northeastern end of Phase I retains the waste in that phase, while another waste dam is located at the northern tip of Phase II. The office building, weighbridge and the maintenance depot are located along the western edge of the site, while the leachate treatment plant is situated immediately north of the Phase II waste dam. An area north of Phase I was undergoing site formation at the time of the site visit. Site management stated that a medical waste incineration plant will be built there, but its date of completion was unknown. An aerial photograph of the site, with major current and future facilities and waste disposal areas labeled, is presented as Appendix IV.

At the time of the site visit, incoming waste was being placed at the edge of a slope in the southeast corner of Phase I; the waste tipping operation is scheduled to move to Phase II later in 2009.

8.2. Environmental Data

According to available meteorological data, the average annual rainfall at Chengdu City is 997 mm, and the average temperature is 17°C. The site is therefore categorized as mildly wet and cool, potentially reducing the rate of waste degradation.

8.3. Waste Depth

Site management indicated that the average waste depth at Phase I was approximately 40m, which is also consistent with what was observed at the current waste disposal area. Future development of Phase II will include a vertical extension at Phase I, with waste to be placed on top after the existing HDPE cover has been removed. It is anticipated that the final average waste depth (with Phase II waste placed on top of Phase I) could reach up to 80m.

8.4. Waste Placement

A waste entry record for January 2009 was provided for review. The average daily waste intake was 4,263 tonnes and the waste was hauled to the site in approximately 500 truck trips. The rate was lower...
than the yearly average reported for 2008 (i.e. 4,900 tpd) due to the Chinese New Year holidays and was expected to rebound in February. The site management reported a peak in waste intake of more than 6,000 tpd in late 2008.

Waste is brought to the site in closed vehicles, offloaded in the tipping area, spread and pushed to the edge of the leading waste slope by both wheeled and track-mounted dozers. A waste compactor was observed, but no compaction operations were ongoing at the time of the site visit.

Site machinery includes one Ingersoll Rand compactor, one Chinese-made excavator, and ten wheeled and track-mounted loaders; all machinery was observed in good conditions. The in-place waste density was reported to be 0.8 tonnes / m³. Based on the reported waste placement techniques, the reported density is considered reasonably achievable.

8.5. Sludge Placement

Wet sludge from a wastewater treatment plant in Chengdu City was disposed in three separate sludge ponds at the southern part of the site. The two smaller ponds were built first and were lined with clay. Construction of the largest pond was completed by late 2007 and was lined with an HDPE liner. Current sludge intake has reached approximately 270 tpd.

8.6. Base Lining

Phase I, built in the early 1990s, was constructed with a clay liner at the base and on the sideslopes. Phase II of the landfill will have a geosynthetic clay liner and an HDPE liner. However, no base lining was observed at the current waste disposal area during the site visit, probably because waste disposal there is considered temporary and scheduled to move to Phase II later in 2009.

8.7. Capping Layer

No daily cover was observed at the active tipping area, while Phase I was observed to have been covered with a 1.0mm HDPE liner. Installation of the liner appeared to be well performed. No surface water ponding or other signs of inadequate grading or differential settlement was observed during the site visit, which took place during a relatively dry period. On top of the liner are many concrete weights which serve to prevent the liner from being lifted and damaged by wind.

Up to twenty HDPE vent pipes were noticed on top of Phase I. These vents were observed to be straight hollow pipes, about 4 inches in diameter and 0.5m long; it appears that they extended only through the HDPE liner to the top of the clay liner. The site management explained that these vents were built to vent gas accumulated between the HDPE liner and the underlying clay liner to minimize “blistering” of the HDPE liner. These vents, although relatively small in diameter, expose the clay liner to the atmosphere and may increase water ingress to the waste. Considering the conditions of the cover at Phase I, it is believed that the resistance to both the escape of landfill gas from the waste and the entrance of surface water to the waste is moderate to good for the site.

8.8. Surface Water Management

Concrete diversion channels have been constructed around the waste disposal area to divert stormwater away from the waste mass. The channels were observed to be in good conditions with no major cracks.
Drainage channels were also noticed on top of Phase I to facilitate runoff and reduce the amount of rainwater from entering the waste.

9. LEACHATE AND GAS

9.1. 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 infiltration of surface water (rainfall). Leachate can be highly contaminated and usually has a very low concentration of dissolved oxygen.

It was reported that a leachate drainage system consisting of perforated leachate collection pipes was built at the base of the landfill during construction in the early 90s. The system was to collect and drain the leachate by gravity to the municipal wastewater treatment plant in Luodai Township. However, the original drainage system became clogged and a replacement drainage system was constructed at a higher elevation, with outlet pipes exiting the waste along the site access road adjacent to the Phase I dam. Current daily leachate generation rate was reported to be 1,200 cubic meters. An on-site leachate treatment plant, reportedly using membrane filtration for treatment, was constructed in 2008. However, the site management stated that the plant was still in the testing and optimization stage at the time of the site visit.

No leachate seepage or outbreaks along sideslopes were observed during the site visit. Also, no facilities existed for the measurement of leachate depth in the waste and no indication of leachate depth was provided by the landfill.

9.2. Gas

It was reported that an active extraction system had been constructed in Phase I, but it was abandoned in early 2009 due to poor gas yield, probably as a result of high leachate levels. The system was built to alleviate landfill gas hazards and was located in the southern portion of the landfill. It comprised of a blower system, two candle stick flares and a number of wells which were built during active waste disposal in Phase I. The gas wells and lateral pipes have been buried under the waste. The capacities of the blower and flares as well as the number and depth of wells were not available.

As indicated in Section 8.7, there were up to 20 passive vents distributed along the slope at Phase I to minimize gas accumulation between the HDPE liner and the underlying clay liner. These vents were up to 0.5m tall and were sealed to the HDPE liner with welded boots. It is not clear how gas below the clay liner is being vented.

Measurements of gas concentration were taken at one of the gas vents at the northern portion of Phase I and at the header pipe outlet prior to entering the flares. The valve that connects the header pipe to the flares is usually closed, but was opened during the site visit to allow gas measurements. The measurements were obtained using a Geotechnical Instruments GA2000 gas analyzer. The measurements are summarized in Table 4 below. A certificate of calibration for the meter used is presented in Appendix II.
Table 4 – Gas Measurements Results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Header Pipe Outlet</th>
<th>Gas Vent</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{CH}_4 ) (%)</td>
<td>63.2</td>
<td>0.1</td>
</tr>
<tr>
<td>( \text{CO}_2 ) (%)</td>
<td>36.2</td>
<td>0.1</td>
</tr>
<tr>
<td>( \text{O}_2 ) (%)</td>
<td>0.1</td>
<td>20.2</td>
</tr>
<tr>
<td>Balance Gas (%)</td>
<td>0.5</td>
<td>79.6</td>
</tr>
<tr>
<td>Atmospheric Pressure (mB)</td>
<td>931</td>
<td>931</td>
</tr>
<tr>
<td>Ambient Temperature (°C)</td>
<td>20.3</td>
<td>20.2</td>
</tr>
<tr>
<td>Gas Temperature (°C)</td>
<td>32.8</td>
<td>20.2</td>
</tr>
</tbody>
</table>

The gas measurement results showed that the methane concentration at the header pipe outlet (63.2% v/v) was at the high end of the range for landfill gas; this indicates that the waste in Phase I is undergoing anaerobic decomposition. The results at the gas vent are similar to those of ambient air; this indicates that at least in the area adjacent to this gas vent the clay liner is acting as an effective barrier to the escape of landfill gas from the waste underneath.

10. GAS MODELING

10.1. 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 model is based on the following equation (Eqn.1):

**Equation 1 - First Order Decay Model**

\[
Q = \sum_{0}^{n} \frac{1}{\%_{\text{vol}} L_0} e^{-k(t-t_{\text{lag}})} kM
\]

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
- \( t_{\text{lag}} \) estimated lag time between deposition of waste and generation of methane.
- \( \%_{\text{vol}} \) 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

### 10.2. Model Parameters

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 5. 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 Chengdu City Landfill and are common at other landfill sites in Asia, with similar moisture content and organic component of the waste. Similar ranges 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 landfill gas generation and recovery at other sites, the upper estimate for landfill gas generation and recovery is oftentimes optimistic, and therefore not conservative from a financial feasibility standpoint. The average estimate represents landfill gas 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 landfill gas recovery and financial performance are estimated based on the lower landfill gas generation estimate with appropriate collection efficiency.

Table 5 shows the model parameters used in the gas model.
Table 5 - 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 m$^3$/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>
<tr>
<td>%vol (Methane percentage volume)</td>
<td>50% v/v</td>
<td>Accepted norm for average methane concentration in landfill gas under extraction conditions.</td>
</tr>
</tbody>
</table>

11. BASELINE RESULTS OF GAS MODEL

Results of the U.S. EPA *LandGEM LFG model* (run with upper, average and lower estimates for $k$ and $L_0$) are given in the following graph (Figure 1) and expected gas production rates for the next 20 years in Table 6.

Using the above values for $k$ and $L_0$, the *LandGEM* model estimates that the site should currently be producing between 3,655 and 5,921 scfm (6,214 and 10,066 m$^3$/hr) of landfill gas at 50% methane and that this emission rate will rise to a peak of between approximately 4,249 and 6,470 scfm (7,223 and 10,999 m$^3$/hr) in 2012, soon after the site is projected to reach design capacity. This gas assessment does not consider the planned phase III because no details were available at the time of the study. If phase III is implemented, gas generation after 2012 will be higher.
Figure 1 - Baseline Landfill Gas Emissions

Table 6 - 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>2009</td>
<td>5,921</td>
<td>4,831</td>
<td>3,655</td>
</tr>
<tr>
<td>2010</td>
<td>6,456</td>
<td>5,287</td>
<td>4,018</td>
</tr>
<tr>
<td>2011</td>
<td>6,429</td>
<td>5,342</td>
<td>4,124</td>
</tr>
<tr>
<td>2012</td>
<td>6,470</td>
<td>5,436</td>
<td>4,249</td>
</tr>
<tr>
<td>2013</td>
<td>5,404</td>
<td>4,726</td>
<td>3,845</td>
</tr>
<tr>
<td>2014</td>
<td>4,514</td>
<td>4,108</td>
<td>3,479</td>
</tr>
<tr>
<td>2015</td>
<td>3,771</td>
<td>3,571</td>
<td>3,148</td>
</tr>
<tr>
<td>2016</td>
<td>3,149</td>
<td>3,105</td>
<td>2,848</td>
</tr>
<tr>
<td>2017</td>
<td>2,631</td>
<td>2,699</td>
<td>2,577</td>
</tr>
<tr>
<td>2018</td>
<td>2,197</td>
<td>2,347</td>
<td>2,332</td>
</tr>
<tr>
<td>2019</td>
<td>1,835</td>
<td>2,040</td>
<td>2,110</td>
</tr>
<tr>
<td>2020</td>
<td>1,533</td>
<td>1,774</td>
<td>1,909</td>
</tr>
<tr>
<td>2021</td>
<td>1,280</td>
<td>1,542</td>
<td>1,727</td>
</tr>
<tr>
<td>2022</td>
<td>1,070</td>
<td>1,340</td>
<td>1,563</td>
</tr>
</tbody>
</table>
12. 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 landfill gas 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 abandoned, the present collection efficiency can only be zero. Information necessary for a detailed evaluation of the collection efficiency that can be anticipated or achieved at the Chengdu 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 landfill gas 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.

13. CALCULATED GAS AVAILABILITY

Based on the above discussion, it is assumed for this assessment that approximately 65% of the landfill gas generated at the Chengdu City Landfill could be recovered for utilization. As discussed in Section 10.2, for this assessment study where conservatism is desirable, the expected landfill gas recovery and financial performance are estimated based on the lower landfill gas generation estimate. Applying the 65% availability factor to the lower estimate in Table 6 gives an estimated available gas flow shown in Table 7.

Landfill methane has a calorific value of approximately 1,012 Btu/cf (or 37.7 MJ/m³); 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 (or 18.9 MJ/m³).

Table 7 also shows the estimated 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>2009</td>
<td>2,375</td>
<td>72.1</td>
<td>21,131</td>
</tr>
<tr>
<td>2010</td>
<td>2,611</td>
<td>79.3</td>
<td>23,231</td>
</tr>
<tr>
<td>2011</td>
<td>2,680</td>
<td>81.4</td>
<td>23,843</td>
</tr>
<tr>
<td>2012</td>
<td>2,762</td>
<td>83.8</td>
<td>24,568</td>
</tr>
<tr>
<td>2013</td>
<td>2,499</td>
<td>75.9</td>
<td>22,230</td>
</tr>
<tr>
<td>2014</td>
<td>2,261</td>
<td>68.6</td>
<td>20,115</td>
</tr>
<tr>
<td>2015</td>
<td>2,046</td>
<td>62.1</td>
<td>18,200</td>
</tr>
<tr>
<td>2016</td>
<td>1,851</td>
<td>56.2</td>
<td>16,468</td>
</tr>
<tr>
<td>2017</td>
<td>1,675</td>
<td>50.9</td>
<td>14,901</td>
</tr>
<tr>
<td>2018</td>
<td>1,516</td>
<td>46.0</td>
<td>13,483</td>
</tr>
<tr>
<td>2019</td>
<td>1,371</td>
<td>41.6</td>
<td>12,200</td>
</tr>
<tr>
<td>2020</td>
<td>1,241</td>
<td>37.7</td>
<td>11,039</td>
</tr>
<tr>
<td>2021</td>
<td>1,123</td>
<td>34.1</td>
<td>9,989</td>
</tr>
<tr>
<td>2022</td>
<td>1,016</td>
<td>30.8</td>
<td>9,038</td>
</tr>
<tr>
<td>2023</td>
<td>919</td>
<td>27.9</td>
<td>8,178</td>
</tr>
<tr>
<td>2024</td>
<td>832</td>
<td>25.3</td>
<td>7,400</td>
</tr>
<tr>
<td>2025</td>
<td>753</td>
<td>22.9</td>
<td>6,696</td>
</tr>
<tr>
<td>2026</td>
<td>681</td>
<td>20.7</td>
<td>6,058</td>
</tr>
<tr>
<td>2027</td>
<td>616</td>
<td>18.7</td>
<td>5,482</td>
</tr>
<tr>
<td>2028</td>
<td>558</td>
<td>16.9</td>
<td>4,960</td>
</tr>
</tbody>
</table>

14. OPTIONS FOR UTILIZATION

A number of options exist for the utilization of landfill gas for industrial and agricultural processes, as well as the generation of electrical energy. The methane content of landfill gas can also be separated from the other components and used to supplement natural gas supplies or, in certain circumstance, 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 world wide.
14.1. **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 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 a medical waste incineration plant is being constructed only 500 m away from the site, it may be economically feasible to transmit the landfill gas to the plant and use it in the incineration process. Additional revenue could be generated if heat or electricity were generated at the incineration plant and sold to a local energy company or other local users. However, whether a direct use project at the medical waste incineration plant is economically feasible will depend on several issues, including the cost of equipping the plant to allow it to use the gas, whether the plant can use all of the available gas, and how much the plant can save and/or earn from the arrangement. 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.

14.2. **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.

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 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 Chengdu 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 via the substation downhill of the site, in combination with direct use of some of the landfill gas.

In the case of Chengdu City Landfill, an excellent candidate that may be able to utilize the landfill gas generated electricity is the on-site facilities (including the leachate treatment plant, office buildings and maintenance depot). Although no estimates of the electricity consumption by the on-site facilities was provided, preliminary analyses indicate that the electricity that can be generated with the projected landfill gas recovery at the site can more than satisfy the needs of the on-site facilities, with excess electricity available for export to the local grid.
15. EMISSIONS TRADING

It is possible to account for, and transfer, the reduction in greenhouse gas emissions (i.e., greenhouse gas 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 Chengdu 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 greenhouse gas 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 Chengdu City Landfill indicates that, prior to early 2009, the site was operating two candle stick flares that destroyed 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. Since the design capacity of the blower and the two flares were not available, it is not possible to determine if they were sufficient to handle all of the landfill gas expected to be recovered at the site. Furthermore, since the existing gas collection system covered only part of the site, the adjustment factor should be less than 100%, potentially allowing some methane reduction credit.

For this study, however, it was assumed that because the Chengdu City Landfill meets the size criteria in GB16889-2008 and because there was an existing gas collection and flare system, the adjustment factor is assumed to be 100% and no direct methane reduction credits would be generated. 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 Chengdu City Landfill as a result of direct methane reduction.

Equation 3 - Available Emission Reductions
\[ T_{\text{Avail, CO}_2} = (1 - AF) \times \%_{\text{vol}} \times 21 \times Q_{\text{Avail}} \times \rho_{\text{CH}_4} \]

Where:

- \( T_{\text{Avail, CO}_2} \): 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%, or a factor of 1, assumed in this case)
- \( \rho_{\text{CH}_4} \): 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 amount 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**

\[ T_{\text{CO}_2} = E_{\text{grid}} \times M_{\text{Wh, exported}} \]

Where:

- \( T_{\text{CO}_2} \): Total emission reduction in Tonnes of Carbon Dioxide Equivalent (tCO2e)
- \( E_{\text{grid}} \): Grid emission factor (0.9735 tCO2/MWh for the Huazhong (Central China) Grid of China [4], which includes Chengdu City)
- \( M_{\text{Wh, exported}} \): Total number of MegaWatt 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 medical 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**

\[ T_{\text{CO}_2} = E_{\text{fossil, fuel}} \times \%_{\text{vol}} \times H_{\text{methylene}} / H_{\text{natural gas}} \times Q_{\text{direct, use}} \]

Where:

- \( T_{\text{CO}_2} \): Total emission reduction in Tonnes of Carbon Dioxide Equivalent (tCO2e)
- \( E_{\text{fossil, fuel}} \): Emission factor (54.71 tCO2/mcf for natural gas)
- \( \%_{\text{vol}} \): Volumetric percentage of methane in landfill gas
\(H_{\text{methane}}\) \(H_{\text{natural gas}}\) \(Q_{\text{direct use}}\)  
Heat content of methane (1012 Btu/cf)  
Heat content of natural gas (1050 Btu/cf)  
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 Chengdu 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 8. Emission reductions produced by the 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 8 are based on the assumption that an enclosed flare is used to ensure a high combustion efficiency (>99%), but that direct methane reduction credits are not obtained (a conservative assumption described earlier in this section). The estimates in Table 8 assume that the efficiency of the electricity generator is approximately 38%.

### Table 8 - 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>2009</td>
<td>0</td>
<td>69,835</td>
<td>32,920</td>
</tr>
<tr>
<td>2010</td>
<td>0</td>
<td>76,774</td>
<td>36,191</td>
</tr>
<tr>
<td>2011</td>
<td>0</td>
<td>78,797</td>
<td>37,145</td>
</tr>
<tr>
<td>2012</td>
<td>0</td>
<td>81,193</td>
<td>38,274</td>
</tr>
<tr>
<td>2013</td>
<td>0</td>
<td>73,466</td>
<td>34,632</td>
</tr>
<tr>
<td>2014</td>
<td>0</td>
<td>66,475</td>
<td>31,336</td>
</tr>
<tr>
<td>2015</td>
<td>0</td>
<td>60,149</td>
<td>28,354</td>
</tr>
<tr>
<td>2016</td>
<td>0</td>
<td>54,425</td>
<td>25,656</td>
</tr>
<tr>
<td>2017</td>
<td>0</td>
<td>49,246</td>
<td>23,214</td>
</tr>
<tr>
<td>2018</td>
<td>0</td>
<td>44,560</td>
<td>21,005</td>
</tr>
<tr>
<td>2019</td>
<td>0</td>
<td>40,319</td>
<td>19,006</td>
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<tr>
<td>2020</td>
<td>0</td>
<td>36,482</td>
<td>17,198</td>
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<tr>
<td>2021</td>
<td>0</td>
<td>33,011</td>
<td>15,561</td>
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<tr>
<td>2022</td>
<td>0</td>
<td>29,869</td>
<td>14,080</td>
</tr>
<tr>
<td>2023</td>
<td>0</td>
<td>27,027</td>
<td>12,740</td>
</tr>
<tr>
<td>2024</td>
<td>0</td>
<td>24,455</td>
<td>11,528</td>
</tr>
<tr>
<td>2025</td>
<td>0</td>
<td>22,128</td>
<td>10,431</td>
</tr>
<tr>
<td>2026</td>
<td>0</td>
<td>20,022</td>
<td>9,438</td>
</tr>
<tr>
<td>2027</td>
<td>0</td>
<td>18,117</td>
<td>8,540</td>
</tr>
<tr>
<td>2028</td>
<td>0</td>
<td>16,393</td>
<td>7,727</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 8. It will be affected by such factors as downtime of the landfill gas collection and utilization system, size and efficiency of the electricity generator or direct use equipment, destruction efficiency of the equipment (such as electrical generator), and parasitic loss efficiency.
16. OUTLINE SPECIFICATION OF A GAS EXTRACTION SYSTEM

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

Landfill gas will be extracted from the site through an array 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 gas wells will vary depending on the location. 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 will be 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 may not achieve combustion efficiencies matching enclosed flares, but they require considerably lower capital costs. Use of a candle stick flare will, however, result in a reduction in the number of emission credits available.

To maximize the destruction of methane, it is necessary to use an enclosed flare, offering above 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%). Considering the predicted gas availability at the Chengdu City Landfill, it may be preferable to use lower cost flare equipment, particularly if most of the landfill gas will be delivered to other utilization equipment.
For the purposes of this study, one gas well was assumed to be installed per acre of the landfill. This assumption should be confirmed through the use of a gas pump test.

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 5 m of waste to minimize air intrusion, while limiting the depth to avoid flooding.

17. FINANCE MODEL

A preliminary financial assessment of alternative landfill gas energy projects at the Chengdu 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 0.9735 tCO2/MWh was adopted for the Huazhong Grid of China.

As indicated previously, 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 LFGcost (especially O&M costs, and to a lesser extent capital costs) should be adjusted downwards for China. 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 Chengdu City Landfill are presented in Table 9. Unless stated otherwise, all “$”s in this report refer to US dollars. An exchange rate of one US dollar to 6.82 Chinese Yuan was used.
Table 9 – Selected Values of Key LFGcost Parameters

<table>
<thead>
<tr>
<th>Key Parameter</th>
<th>Selected Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area of Wellfield</td>
<td>86 acres (35 Ha)</td>
</tr>
<tr>
<td>Average waste depth</td>
<td>257 ft (78.5 m)</td>
</tr>
<tr>
<td>Distance between landfill and direct end user (for Direct Use project only)</td>
<td>5 miles</td>
</tr>
<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>6.5%</td>
</tr>
<tr>
<td>General Inflation Rate</td>
<td>3%</td>
</tr>
<tr>
<td>Equipment Inflation Rate</td>
<td>4.5%</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>$0.037/kWh</td>
</tr>
<tr>
<td>Initial year LFG product price</td>
<td>$4.01/mmBtu</td>
</tr>
<tr>
<td>Initial year electricity product price</td>
<td>$0.0616/kWh</td>
</tr>
<tr>
<td>Annual product price escalation rate</td>
<td>8%</td>
</tr>
<tr>
<td>Electricity purchase price</td>
<td>$0.103/kWh</td>
</tr>
<tr>
<td>Annual electricity purchase price escalation rate</td>
<td>9%</td>
</tr>
</tbody>
</table>

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

In addition, certain key assumptions embedded in LFGcost are listed in Table 10:

Table 10 – Key LFGcost Assumptions

<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 90% for Direct Use</td>
</tr>
<tr>
<td>Parasitic Loss Efficiency</td>
<td>92% for Standard Reciprocating Engine-Generator</td>
</tr>
</tbody>
</table>

Based on the moderate amount of landfill gas estimated to be available at the Chengdu 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. To be conservative, it was assumed that the existing blower and flares will not be incorporated into the new system; therefore, the cost of a landfill gas collection system and backup flare were included in both analyses. In addition, even though the distance from the landfill to the
planned medical waste incinerator could be as short as 500 m, the distance between the landfill and direct end user was assumed to be 5 miles in the analyses to be conservative and in case a different direct use farther from the landfill is identified.

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 tCO₂e 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 greenhouse gas 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 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 greenhouse gas credits, and the other assuming none of the direct methane reductions qualify.

However, due to the fact that there are two existing candlestick flares (though not being operated) that can handle some of the landfill gas expected to be recovered at the site, it is likely that only a limited fraction of the direct methane reduction would qualify for greenhouse gas credits at this site (refer to discussion on Adjustment Factor in Section 15), even if GB16889 does not apply to this landfill. Therefore, to be conservative, variation of this parameter was not evaluated in the financial model (this is consistent with the assumption of 100% for the Adjustment Factor). It was assumed that the direct methane reductions at the landfill would not qualify for greenhouse gas credits; however, it would still qualify for credits for CO₂ 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 11 and 12. 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 11 – 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 4,969kW</td>
<td>$11,410,871</td>
<td>$1,271,554</td>
<td>IRR 34.6%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>NPV $7,486,194</td>
</tr>
<tr>
<td>Direct Use</td>
<td>$6,411,532</td>
<td>$971,172</td>
<td>IRR 47.4%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>NPV $5,130,633</td>
</tr>
</tbody>
</table>

The above LFGcost results indicate that for scenarios corresponding to crediting period ending in 2012, both an electricity generation project using standard reciprocating engines and a direct use project are feasible for the three assumed emission reductions prices. A direct use project would have a higher IRR for a given emission reductions price, while an electricity generation project would have a higher NPV.

Similarly, for scenarios corresponding to crediting period ending in 2024 or beyond, both an electricity generation project using standard reciprocating engines and a direct use project are feasible for the three assumed emission reductions prices. Again, a direct use project would have a higher IRR for a given emission reductions price, while an electricity generation project would have a higher NPV.

It should be emphasized that the positive financial feasibility of a direct use project is valid only if arrangements can be made with an end-user within a reasonably short distance from the site to utilize all or most of the recoverable landfill gas or if potential end-users can be persuaded to set up operations close to the site. For the Chengdu City Landfill, the planned medical waste incineration plant may be a viable user for the recoverable LFG, but further investigation and evaluation is necessary.
The $LFG_{cost}$ model accounts for the cost of collecting the gas and piping it to a potential user (such as the medical waste incineration plant), but does not include any costs that might be needed to modify the combustion equipment at the potential user’s facility to use LFG.

The above analyses assumed the energy product (landfill gas or electricity) would be sold and used off-site. The project’s financial feasibility might be improved if some or all of the landfill gas or electricity was used on-site by the project itself instead, as the financial benefit (in the form of reduced expenditure) would likely be higher than the revenue that it can bring in from its sale. However, further detailed evaluation would be needed to determine whether on-site self use should be pursued; factors to be considered include the amount of energy required for self-use (compared to the amount of energy available from the LFG); the feasibility of utilizing the remaining energy left after self-use (if any); how to supplement the LFG-generated energy if more energy than available is required; etc. Also, it is uncertain whether the Renewable Energy Credit is applicable if the electricity generated was used at the site instead of exported to the grid.

It should be noted that the above evaluation assumed that the regulation stipulating the provision of $0.037/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.

As discussed previously, the above evaluation assumed that direct methane reductions at the landfill does not qualify for greenhouse gas credits based on a conservative interpretation of GB-16889 and assessment of the Adjustment Factor for the existing flares. It is possible to argue that some (or all) of the direct methane reductions should qualify for greenhouse gas credits; if successful, the project’s financial feasibility could be enhanced substantially.
18. CONCLUSIONS

The analyses documented in this assessment report indicate that the Chengdu City Landfill produces a significant and relatively steady amount of LFG, and that a landfill gas utilization project could be technically and financially feasible.

The financial feasibility and the types of energy projects that may prove to be feasible would generally depend to a large extent on the crediting period during which emission reductions are valid and the price of emission reductions. However, for the Chengdu City Landfill, both an electricity generation project using standard reciprocating engines and a direct use project are feasible for the three assumed emission reductions prices, whether the crediting period ends in 2012 or in 2024.

Consideration of current energy costs and emission reduction pricing over the crediting periods does not clearly favor either one of the two options for an energy recovery project at the Chengdu City Landfill. Landfill gas generated electricity can be used to meet the power needs of on-site facilities such as the leachate treatment plant, with excess power sold off-site through a grid connection. However, to implement a direct use project, a viable end user within a reasonable distance from the site must be identified. The planned medical waste incineration plant may be a viable user. Other industrial processes could potentially be sited near or on the landfill site to utilize landfill gas-fueled heat or power.

Financial feasibility is also contingent upon the implementation of proper solid waste management practices required to achieve a reasonable level of landfill gas production and improved gas collection efficiencies.
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: Chengdu City Landfill, Chengdu

LFGE Project Type: Standard Reciprocating Engine-Generator Set

Date: Thursday, May 14, 2009

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: $8,100,894 (at year of construction)
- Internal Rate of Return: 39%
- Net Present Value Payback (yrs): 4 (years after operation begins)
- Capital Costs: $11,410,871
- O&M Costs: $1,271,554 (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): 7,258
- Lifetime (MMTCO$_2$E): 2.92E+00
- Average Annual (million ft$^3$ methane/yr): 484
- Average Annual (MMTCO$_2$E/yr): 1.95E-01

Benefits from Avoided Electricity Generation from Fossil Fuels (during the life of the project):
- Lifetime (MMTCO$_2$E): 4.53E-01
- Average Annual (MMTCO$_2$E/yr): 3.02E-02

Landfill Characteristics

Open Year: 1993
Closure Year: 2011
- Waste-In-Place at Closure (tons): 7,207,355
- Average Waste Acceptance (tons/yr): 400,409
- Average Depth of Landfill Waste (ft): 257
- Area of LFG Wellfield to Supply Project (acres): 86
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: 1,339
- Annual Average: 2,833
- Maximum: 4,444

Collected During Project Lifetime (ft³/min):
- Minimum: 870
- Annual Average: 1,841
- Maximum: 2,889

Project Size: Average

Design Flow Rate for Project (ft³/min): 1,841

Utilized by Project (ft³/min):
- Annual Average: 1,428

LFG Collection Efficiency: 65%

Financial Assumptions
- Loan Lifetime (years): 10
- Interest Rate: 6.5%
- General Inflation Rate: 3.0% (applied to O&M costs)
- Equipment Inflation Rate: 4.5%
- 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): 4,969
- Average Generation (million kWh/yr): 31.052 (during the life of the project)
- Initial Year Electricity Price ($/kWh): 0.061583578
- Price to Achieve Financial Goals ($/kWh): 0.045 (determined by Financial Goals Calculator results)
Landfill Gas Generation, Collection, and Utilization Curve

- **Average Annual Landfill Gas Flow Rate (ft³/min)**
- **Year**
- **Gas Generation**
- **Gas Collection**
- **Gas Utilization**

- **Report - 4**
APPENDIX II

CERTIFICATE OF CALIBRATION
GAS ANALYZER CALIBRATION REPORT

Calibration Date: 23-Mar-09

DETAILS OF EQUIPMENT TO BE CALIBRATED

Equipment: CES-Landtec Portable Landfill Gas Analyzer
Model: GA 2000
Serial Number: GA11224

Measurement 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.

CALIBRATION GASES USED

Certificate No.: T08/03950
Cylinder No.: P6176
Composition:
- 14.8% N₂
- 35.7% CO₂
- 49.5% CH₄
- 0.0% O₂

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

Conclusion: Adjustment of GA2000 not necessary

Reported by: [Signature]

Checked by: [Signature]
APPENDIX III

LANDFILL LOCATION MAP
Landfill Location Map

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

LANDFILL AERIAL VIEW
Aerial View of Chengdu City Landfill, Chengdu City, Sichuan Province, China
(Photo Date: Early 2008)

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

SELECTED PHOTOGRAPHS
Photo 1: Panoramic View of the Landfill from the East

Photo 2: Panoramic View of the Landfill from the South
(From Left to right: Phase II under construction, Sludge Pond, Phase I Waste under HDPE cover)
Photo 3: Entrance to the Landfill Site Office

Photo 4: Weighbridge adjacent to the Landfill Entrance
Photo 5: On-site Machinery Maintenance Depot

Photo 6: Trucks entering Active Waste Tipping Area
Photo 7: View from below the Leading Edge of the Active Waste Tipping Area

Photo 8: A Close-up View of Disposed Waste
Photo 9: A View of Phase II under Construction
(Note leachate drainage pipe running along the edge of access road)

Photo 10: Surface Water Diversion Channel along the Perimeter of Phase I
Photo 11: Surface Water Drainage Channels on the Slope of Phase I

Photo 12: QA/QC markings on the HDPE membrane cover on Phase I
Photo 13: Gas Measurements at one of the Vent Pipes in Phase I

Photo 14: Dormant Flaring System at Site
(Note the high voltage transmission lines south of the landfill in the background)