

Landfill Gas Capture



Design vs. Actual Performance and the Future for CDM Projects

Document Prepared by:

Horacio Terraza
Hans Willumsen
Helvecio Guimaraes

Sponsored by



Canadian International Development Agency Agence canadienne de développement international

Organized by



THE WORLD BANK

Background

Climate change recently has become the top environmental priority on many government agendas. Concerns about the earth's environmental balance have risen significantly with the record-high temperatures experienced in the past few years. International, regional, and local policies and mechanisms have been negotiated or are under discussion to pave the way for the stabilization of the planet's climate patterns.

The most notable of all the accords, the Kyoto Protocol, entered into force in February 2005, and its formal institutionalization cemented the international carbon market foundations. The Clean Development Mechanism (CDM), one of the three flexibility mechanisms established under the Protocol for achieving emission reductions, has received most of the world's attention when it comes to project-based greenhouse gas (GHG) emission reductions (ERs) solutions.

By mid-April 2007, more than 600 projects were registered in the official CDM database, meaning that those projects had passed all the documentation and analyses required for generating ERs. Of these, 44 were landfill gas (LFG) capture projects, aiming to generate ERs through flaring the methane present in LFG.

As these projects were developed, implemented, and operated, the rationale for—and the flaws in—the engineering needed to get these kind of initiatives up and running in the developing world, where landfills, technically speaking, are not the norm, became more apparent. The main evidence of problems, related either to poor design or to operation of the LFG plants or the landfills themselves, was seen in the difference between the ERs projected in the validated Project Design Documents (PDDs) and official CDM project document and the ERs actually achieved once the projects started capturing and flaring LFG.

Objective

In order to understand better the apparent under-performance of LFG projects in the developing world, the World Bank Latin America and the Caribbean Environment Group and Carbon Finance Unit organized a workshop in Washington, DC, on April 19, 2007. Sponsored by the Canadian International Development Agency (CIDA), the workshop brought together representatives from six projects under both the CDM and the Global Environmental Facility to present details about the design and operation of their projects and landfills and measures they had considered to increase LFG capture and thus ERs.

Besides the case studies, the workshop included presentations from three LFG experts who spoke on the CDM LFG portfolio and LFG modeling.

This report presents information gathered for the workshop, as well as findings and conclusions reached during the event.

Baseline Information

To ensure the collection of minimal and pertinent information for the proposed analyses and presentations in the workshop, a questionnaire was developed and distributed to the representatives of the six projects. This questionnaire included mainly technical questions on the design and operation of the LFG plants and landfills. The presenters were asked to prepare presentations based on the content of the questionnaire, shedding light especially on landfill engineering and operation, LFG modeling, and LFG plant design and operation.

Modeling Discussion

Two presenters, Ms. Susan Thorneloe from the U.S. Environmental Protection Agency (EPA) and Ms. Jean Bogner from Landfills+, Inc., were invited to discuss issues around modeling LFG generation. Bogner pointed out, among other things, that models usually assume that landfills are well-mixed, optimized anaerobic digesters, leading to considerable uncertainties in LFG prediction. In fact, according to Bogner, actual LFG production has ranged from less than 50 percent to more than 200 percent of that assumed in the theoretical models. Among the causes for such variability, she pointed to (i) the inappropriate choice of models or input parameters, (ii) the application of long-term models to predict short-term trends, and (iii) field operational issues such as landfill engineering and placement of cover materials, waste in place reachable either with horizontal or vertical gas wells, and gas collection efficiency.

Thorneloe discussed some recent developments in the EPA's approach to LFG modeling, as well as LFG issues and concerns the agency deals with. The EPA's most immediate concern is the risk of explosions and landfill fires. Moreover, landfill emissions of concern include greenhouse gases, volatile organic compounds, hazardous air pollutants, persistent bio-accumulative toxics, hydrogen sulphide, and molecular hydrogen (H_2). Thorneloe explained that the EPA's approach to quantifying LFG emissions uses a first order decay model to predict emissions over time. Default factors for model inputs are based on analysis of gas recovery data. She also mentioned that the EPA uses commercially available technology to assess gas capture and control in U.S. landfills. Such technology, called optical remote sensing (ORS), involves surveying the landfill area to identify LFG hot spots and quantify fugitive emissions through a laser system. Thorneloe concluded her presentation with the overall status of EPA's LFG activities. Recently concluded activities include LFG fugitive loss measurement at wet/bioreactor landfills using ORS, complete gas recovery data compilation from full-scale operating wet/bioreactor landfills, preparation of guidance to estimate LFG from older landfills, measurements that will provide comprehensive analysis of constituents in raw LFG and also in combustion by-products, and data on the presence of mercury in LFG. Among the EPA's main ongoing activities, Thorneloe mentioned efforts to update its factors for LFG modeling, including not only data for LFG generation prediction, but also factors that will allow prediction of by-products formation according to LFG flaring technology and data on pollutants not considered before, such as organo-mercury compounds.

Case Studies

The case studies presented in the workshop included landfill gas projects in six countries.

Bandeirantes Landfill-Gas-to-Energy Project, São Paulo, Brazil

The Bandeirantes Landfill is one of the largest landfills in Brazil. Located in São Paulo in the southeast of the country, the landfill received an average of 5,000 tons of waste per day in 2006. This amount roughly corresponds to the municipal solid waste generated by the city of São Paulo daily.

The landfill, which is the property of the municipality, was opened in 1979 and is scheduled to close in 2007. It covers an area of about 150 ha and has an average depth of 26 m. An estimated 30 million tons of waste, 70 percent of which was municipal solid waste (MSW), have been disposed of in the landfill. Waste is compacted and covered daily with a silty clay cover. The landfill's final cover will be a 60 cm layer of clay. Figure 1 shows an aerial overview of the landfill.



Figure 1. Bandeirantes landfill aerial overview

Extraction of LFG from Bandeirantes began at the end of 2003, with the start-up of the gas and electricity generation plants. Projected to extract around 18,000 m³ of LFG per hour (from a 46 ha landfill area) and generate around 175,000 MWh of electricity per year, the initiative in São Paulo is one of the largest in the world in its category. The gas plant was developed as a partnership between a Dutch company and a Brazilian company.

To design the gas plant, test pumps were carried out in three vertical wells over 8 weeks. A proprietary model was then used to predict LFG generation and extraction from the site. For CDM purposes, however, the results were translated to the Intergovernmental Panel on Climate Change (IPCC) first order decay model. This translation resulted in a factor k (decay rate) equal to 0.105 year⁻¹ and a Lo factor (methane generation potential) equal to 0.055 tCH₄/t waste.

According to the predicted estimates, the project performed poorly in 2006. Only 103,000,000 m³, or 48 percent, of the estimated 215,000,000 m³ of LFG to be captured reached the gas plant. Although the captured amount was enough to feed the electricity plant, the LFG that was not captured, if in fact it was generated at the landfill, represented potential revenue losses from the commercialization of ERs under the CDM framework.

The project representatives highlighted the following among the major issues causing the under-performance of the Bandeirantes landfill:

- Landfill settlement, which caused many concrete wells to break, blocking the gas passage
- Poor landfill cover, resulting in LFG loss to the atmosphere. Tests have shown that an average of 0.050 Nm³/h/m² of LFG escapes the landfill.

Villa Dominico Landfill Gas Project, Buenos Aires, Argentina

The Villa Dominico landfill is located east of Buenos Aires, Argentina's capital, on the margins of the La Plata River. During its active life, from 1990 to 2002, the landfill received an average of 7,000 tons of waste per day, including MSW and industrial waste.

The landfill is owned by the *Coordinadora Ecológica Area Metropolitana Sociedad del Estado*, or CEAMSE, a public entity whose shareholders are the Municipality of Buenos Aires and the province of Buenos Aires. The waste disposal site covers 505 ha, and gas is extracted from 76 ha. Waste disposal started in 1978, and operations ceased in 2004. On average, the landfill has a depth of 15 m, and an estimated 32 million tons of waste have been disposed of in the area. Approximately 25 million tons of this waste is under the influence of the landfill gas capture network. Waste used to be compacted and covered daily, and a 60cm final clay cover had been applied to the landfill by the time of its closure. Figures 2a and 2b show aerial overviews of the Villa Dominico landfill.



Figures 2a and 2b. Villa Dominico landfill aerial overviews

The LFG plant in Villa Dominico was engineered using the Rettenberger model. This is a first order decay model similar to that of the EPA and thus that of the UNFCCC. In Villa Dominico a decay rate k of 0.035 was used. The Rettenberger model does not require an explicit L_0 value to estimate LFG generation. Instead, the model relies on a series of variables to estimate methane generation from the waste. These data include the waste's organic carbon content and temperature. Pump tests were also carried out at Villa Dominico to allow better understanding of the gas quality and quantity at the landfill. Tests were carried out on four isolated wells (over 3 days), five combined wells (over 3 days) and two horizontal drains. Two sets of tests had a short life because of the presence of leachate in the wells, which led the developers to try the horizontal drains.

According to the estimates presented in its PDD, the Villa Dominico LFG Project has performed well below expectations. In 2006 the project predicted the extraction of approximately 13,300 Nm^3/hour of LFG, but only an average of 1,500 (11.8 percent) Nm^3/hour was actually captured and flared. Although it is impossible to confirm whether the other 88 percent was generated at the landfill, this apparent under-performance is related mainly to the very high leachate levels at the landfill (4 m under the surface). Although the landfill site has a leachate treatment plant, the installed capacity cannot handle the excess leachate that would be actively extracted from the landfill.

Las Rosas Landfill-Gas-to-Energy Project, Maldonado, Uruguay

The Las Rosas landfill is located in Maldonado, Uruguay, a city of 140,000 inhabitants located 140 km east of the capital, Montevideo. The landfill, municipally owned and privately operated, consists of two waste cells and an intermediary mini-dump. Approximately 519,000 tons of waste has been landfilled in these three spots. The first cell operated from 1997 to 2001, and

the third is scheduled to close in 2007. For a short time in 2004–2005, the intermediary mini-dump received some 45,000 tons of waste. Overall, the cells have counted on daily compaction and cover (clay or 50 μm polyethylene film), but no geomembrane is applied to the bottom of the two landfill cells. Leachate is collected and treated on site.

The LFG plant was designed and constructed by an international consortium that used a proprietary model to estimate the LFG capture potential from the site. Details on modeling for this plant unfortunately were not disclosed. No pump tests were carried out in the LFG estimation. In late 2005, after a pre-feasibility study for the Felipe Cardoso landfill in Montevideo, the engineers working in Las Rosas again modelled the LFG capture potential using the EPA's first order decay model. In the modeling exercise, the engineers used k values of 0.28, 0.056, and 0.014 year^{-1} , depending on the type of waste, and a methane generation potential L_0 of 94 $\text{m}^3 \text{CH}_4/\text{t}$ waste. For 2006, the model exercise resulted in an expected capture of 1,963,000 m^3 of LFG, whereas only 1,496,000 (76 percent) was extracted.

Several reasons were cited for the lower-than-expected performance at Las Rosas. Leachate presence in gas wells was constant since project start-up, even though the use of leachate pumps from mid-2005 considerably improved the plant's LFG capture profile. Moreover, the plant operated for most of 2006 without portable gas analyzers, which are necessary for measuring individual wells' performances and thus generate much-needed information regarding possible problems in the gas pipes or the wells themselves. Also, two long dry periods since the plant started operating caused the final cover of cell 1 to crack, reducing its sealing factor and allowing air into the cell, thus reducing the LFG quality.



Figure 3. Landfill-gas-to-energy plant in Las Rosas landfill

Olavarría Landfill Gas Recovery Project, Olavarría, Argentina

Located in the center of Buenos Aires Province approximately 350 km southwest of the capital of Argentina, Olavarría is a town with a little more than 100,000 inhabitants. In recent years, the average daily waste generation has been between 80 and 100 tons per day. This waste is sent to the city's landfill, which is 5 km from the city limits. While the total area reserved for waste disposition is about 34 ha, the landfill's two cells cover around 4 ha only. The operation of the landfill, carried out by a private concessionaire, started in 1999. At present approximately 238,000 tons of waste have been disposed of at the site, with about 180,000 tons disposed of in cell 1, where the LFG extraction system is installed. Both cells have geomembrane installed as bottom liners, and leachate is treated on site. Waste is compacted daily and covered with local soil weekly. The same type of cover was applied to cell 1 when it closed.

The LFG plant in Olavarría was designed locally using the Canyon-Scholes model (first order decay) as a reference. The decay rate k was assigned a value of 0.099 year^{-1} , whereas the methane generation potential L_0 equaled $102 \text{ m}^3 \text{ CH}_4/\text{t}$ of waste. For assurance purposes, before the flare was built, a one-day pump test was carried out at the extraction wells. In 2006, only about 20 percent of the estimated $3,408,000 \text{ m}^3$ of LFG, or $677,000 \text{ m}^3$, was captured. Moreover, LFG quality in this case was also very poor: on average, methane content in 2006 was 29 percent.

One possible reason for under-performance in Olavarría is the inadequate final cover at cell 1. The local soil may not be suitable for landfill cover if it is highly permeable, and poor compaction may allow air into the landfill. This dilutes the methane present in the LFG and compromises the desired results. Furthermore, leachate presence in the wells impedes gas extraction.



Figure 4. Cover works in Olavarría's landfill

Grobina Polygon Landfill-Gas-to-Energy Project, Liepaja, Latvia

Liepaja is the third largest city in Latvia. With a population of approximately 87,000 (140,000 in the region of Liepaja), the city is located 220 km west of Riga, the capital, on the Baltic coast. The Grobina Polygon landfill started operations in September 2004 and until December 2006 received approximately 90,000 tons of waste (an average of 130 tons per day), both domestic (85 percent) and non-domestic, including industrial, construction, garden and sludge wastes (15

percent). Of the fifteen energy cells designed to receive the waste, two are already full, with another two receiving waste as of the day of the workshop. The closed cells have a 0.5 m clay cover plus a 0.2 meter soil cover. The average depth of the cells (closed and in operation) is approximately 8 m, while the area covered is approximately 2.4 ha. Before cell closure, the waste is covered only quarterly, although compaction is part of the landfill's daily operation. The cells have geotextile and high-density polyethylene membranes covering the bottom, and any leachate generated is collected and treated on site in anaerobic ponds. The landfill is expected to have a 20-year life.

The idea of operating an LFG plant at the Grobina site was conceived along with the landfill engineering. Thus, dealing with the gas plant and its management has been an integral part of the solid waste operation at the site. The LFG generation modeling was carried out by an international contractor who used a Dutch (LFG Advisory Centre) model. No pump test was carried out, and unfortunately the contractor never made the model parameters available. Some of the assumptions during the LFG plant design considered 2004 as first year of operations and no waste classification prior to final disposal. At present LFG is being extracted from an area where approximately 41,000 tons of waste have been disposed of. In 2006 approximately 561,000 Nm³ (80 percent) of the targeted 696,000 Nm³ of LFG to be captured was actually captured and flared. LFG quality, nevertheless, has not been disappointing. Methane content averaged 42 percent in 2006.

Some factors have been pointed out as possible causes of the under-performance in the Grobina LFG plant. For instance, the dry weight of the organic fraction in the waste turned out to be 29 percent, compared with the 37 percent envisioned by the landfill owners. Moreover, while the cells were designed to allow for leachate recirculation and thus to increase moisture and boost gas production, leachate is being treated in anaerobic ponds. In fact, even the minimum moisture conditions are not being achieved. This is certainly increasing the time the waste's organic fraction takes to decompose.



Figure 5. Grobina Polygon aerial overview
SIMEPRODESO-Benlesa Landfill-Gas-to-Energy Project, Monterrey, Mexico

Monterrey is the capital of Nuevo León State in northeast Mexico and part of the third-largest metropolitan area in the country. The *Sistema Metropolitano de Procesamiento de Desechos Sólidos* (SIMEPRODESO) landfill is located on the north side of Monterrey, in the district of Salinas Victoria. The landfill was established on a green-field site with a total landfill area of 220 ha. Since operation began in 1991, the landfill has accepted mostly non-hazardous domestic and commercial waste, as well as some non-hazardous hospital and industrial waste. Approximately 80 percent of the waste received is municipal solid waste. Although the landfill continues to receive waste, the area where gas is extracted is closed. This area covers about 56 ha, has an average depth of 20 m, and contains approximately 8.7 million tons of waste. Leachate is extracted through vertical wells, and the waste is covered daily. Closed cells also receive a final clay cover.

The LFG-to-energy plant in Monterrey has been in operation since 2003 and was designed and implemented as a GEF operation managed by the World Bank. Currently there are three open flares with a capacity to flare 5,000 m³ of LFG each and seven 1.06 MW gas engines installed and operating at the plant.



Figure 6. Monterrey's SIMEPRODESO landfill satellite view

To model the LFG generation potential, the U.S. EPA first order decay model was used. The critical L_0 and k parameters used were drawn from U.S. data following adaptation to local conditions. In the case of L_0 , adjustments were firstly made considering the relationship between apparent L_0 values and actual LFG generation in U.S. plants. Then the Mexican factor was again adjusted, this time to take into account the different organic content between U.S. and Mexican wastes. The Mexican developers then settled on a L_0 of 95.4 m³ per ton of waste.

In the case of k , the engineers in Mexico used the so-called Method 2E from the U.S. EPA (<http://www.epa.gov/ttn/emc/promgate/m-02e.pdf>). This method allows for an estimation of k based on the gas well area of influence and thus the amount of waste contributing to gas generation at that specific well. In summary, a pump test is carried out in a gas well and, after the gas flow achieves a steady state, the radius of influence of the well is calculated with the help of probes that measure gas pressure at different distances from the well. Once the waste quantity associated with that gas flow is determined, the EPA model can be used to calculate k . In Monterrey the site tests led to a k of 0.0606 per year, in line with previous studies that had shown a k of 0.066 per year.

The plant, as designed, has performed well above expectations. In 2006 it extracted 31.2 million Nm³ of LFG, or 103 percent of the estimated 15.9 million Nm³. This has allowed the design of a second phase, in which another 5 MW will be installed.

Case Study Analysis

The case studies presented at the workshop provide a rich source of experience and information related to LFG plant design and operation. Most of the landfills described are facing under-performance problems. In general the underlying causes of such problems differ, although some issues are common. The following discussion of landfill operation, LFG modeling, and LFG plant operation sheds light on the major issues.

1. Landfill Operation

Landfill operation is doubtless a major determinant of the performance of the LFG plants. Adequate conditions for waste decomposition, including temperature, waste compaction, and moisture, as well as perfect interaction between the landfill and the LFG plant operations, are needed to maximize gas extraction and quality. Generally, landfills are poorly operated across the developing world and do not present these optimal conditions for LFG extraction. Moreover, most of the LFG projects in these areas were implemented in landfills that were not envisioned to have active gas recovery, a fact that tends to lead to a clash between landfill and LFG plant operations.

For example, only two of the six landfills in the case studies, Maldonado and Monterrey, use daily coverage practices. The other four either do not apply any temporary cover or apply it less often than recommended (Olavarría, weekly; Bandeirantes, quarterly.) Lack of daily coverage, besides contributing to pest and rodent dissemination, favors aerobic decomposition of waste and thus minimizes the methane generation potential of old landfilled waste. Moreover, the soil layer used to cover waste daily constitutes an important seal against air intrusion in the landfill once an LFG active recovery system is installed. Without these barriers, air is prone to be sucked into the waste mass when the LFG plant is operating, thus diluting the LFG and lowering the gas quality.

A similar rationale applies to the final cover. Without a compact, almost impermeable, cover, air tends to enter a landfill and reduce the LFG quality, besides allowing some LFG to escape. Olavarría is an interesting case. Made of soil instead of clay and lacking reasonable compaction, the landfill's final cover is the major cause of the very poor LFG extracted (29 percent CH₄ on average in 2006.)

The Bandeirantes landfill is another interesting case regarding final cover. The LFG operator has been capturing an average of 60 percent–65 percent of the original estimates since the plant started operating in December 2003. After battling many factors to improve plant performance, the operator opted to carry out tests to estimate the LFG that was migrating to the atmosphere through the landfill's surface. Installing four caps in four different areas on the landfill's surface, the LFG operator measured average CH₄ surface flow of 0.050 Nm³/h/m². After considering the whole surface from where the gas was extracted, the operator realized that between 9,400 Nm³/h and 24,000 Nm³/h of LFG (50 percent CH₄) was escaping because of poor waste coverage. This shortfall could easily explain why the target estimates were not reached. Currently the operator is studying covering the whole surface with high-density polyethylene to capture more LFG.

Leachate management is another critical factor in landfill operations that has a major impact on LFG extraction. Without adequate handling, leachate can accumulate in the landfill and clog gas wells, preventing any LFG from getting out of the site through the extraction facilities. Unfortunately, landfill facilities around the developing world tend to be poorly designed and therefore lack adequate leachate management, whether it is collection for treatment or recirculation. Two of the case studies (Maldonado and Villa Dominico) highlighted the leachate problem for LFG extraction on different scales.

In the case of Maldonado, as soon as the gas wells were being drilled, the engineers noticed that leachate could be a problem because some wells quickly filled up. When the plant started operating, local tests showed that the wells with leachate were considerably under-performing in relation to their closest, driest neighbors. To address the issue and improve the plant's performance, the engineers installed individual pumps in problematic wells to extract the leachate. This considerably improved the plant's performance, roughly doubling the amount of gas captured.

The Villa Dominico landfill situation is much more serious than Maldonado's. Lacking an adequate leachate management system, the landfill operated from 1978 until the beginning of 2001 without proper collection of any percolated liquid. After a study in 2001 found that the leachate was confined within the landfill, a leachate treatment plant was built to deal partially with the problem. Unfortunately, this plant was not designed to manage all the leachate, but only part of it. Thus, the engineers in charge of designing and building the LFG plant opted for horizontal wells instead of vertical ones, as the leachate level was about 3 m under the landfill surface. Considering that the landfill has an average depth of 15 m, it is easy to see that a huge part of the site's LFG potential remains untapped. It is no wonder that the LFG operator has been struggling to extract a little less than 10 percent of the original LFG estimates.

2. LFG Modeling

LFG modeling is a difficult exercise. Equally difficult is analyzing the quality of the design of an LFG plant. It is not always certain that LFG exists as stated in the modeling exercise results, and thus that landfill operation conditions or LFG plant equipment can be blamed for apparent under-performance. Conversely, it is not always certain that the gas captured is not only a fraction of the gas produced, even though this fraction corresponds to the modeled estimates.

Despite such rather philosophical questions, LFG modeling is not abstract. Models evolved in recent years as a considerable number of plants were built and large amounts of data became available. Multi-phased models replaced simpler versions to account for different types of waste landfilled and specific moisture and other relevant conditions throughout the landfills' lifetime. Also, new techniques to measure the radius of influence of gas wells have allowed pump tests to provide critical information for adjusting models to specific local conditions.

LFG modeling followed different paths in each of the case studies presented at the workshop. In Bandeirantes, three wells were tested for two months. LFG flow results were consistent in two of

the wells, with average biogas flows of 154 Nm³ and 133 Nm³ per hour, but the third showed an average biogas flow of only 41 Nm³ per hour. On the other hand, methane content in the three wells was similar, with an average of 59.7 percent. With the pump tests results, a proprietary model was used to estimate gas generation in the two target cells (the newest ones). Nevertheless, considering that CDM rules require that LFG projects use publicly accessible models, the developers adjusted the results obtained with the proprietary model to the U.S. EPA's first order decay, using a k factor (organic decay speed) of 0.105/year and a Lo factor of 0.055 tCH₄/t of waste.

In Villa Dominico, a proprietary model based on the Rettenberger model, also a first order decay prediction tool, was used. As in the case of Bandeirantes, prior to estimating the gas, pump tests were carried out on site. Nevertheless, the tests had relative success, as the three wells drilled for the tests filled with leachate after 3 days. The solution was to carry out the pump tests using horizontal wells, thus in fact analyzing only a fraction of the gas generation potential of the landfill. In the end, a k factor of 0.035/year was used.

No detailed information is available on the model used to design the Maldonado plant; the contractors denied access to any information relating to the plant's design except the technical specifications. Nevertheless, to better understand the potential resources of the site, the plant operator adapted the U.S. EPA's first order decay model to a proprietary model and ran it using decay and methane generation factors that had been estimated for the landfill in Montevideo as part of the LFG Initiative's third phase. The engineers in Maldonado used three different decay factors to account for the different types of waste landfilled in Las Rosas. They used a value of 0.28/year for the high degradable waste (59.3 percent of the waste mass); 0.056/year for the medium degradable waste (10.5 percent); and 0.014/year for the low degradable waste (3.3 percent). This approach allows a more accurate estimate of the gas generation as different wastes degrade, and therefore produce methane, over different amounts of time. The engineers at Las Rosas used a Lo factor of 68 Nm³ of CH₄/t of waste throughout the modeling exercise.

Olavarría's project design was based on the Canyon-Scholl model, which also uses a first order decay rationale to estimate LFG generation. Pump tests were carried out in Olavarría after the wells were drilled, but before the flares were built. The test took just a day and was more a routine procedure to verify that the wells had been built properly than a procedure to check gas generation conditions at the site. In this project, a decay rate of 0.099/year was used. The model also counted on a Lo factor of 102 m³/t CH₄ to estimate the future gas generation in Olavarría's landfill.

The Grobina Polygon LFG plant design shares some similarities with Maldonado's. Even though a contractor was hired to design the plant and model the LFG generation at the site, details of the model used were never discussed. The only information the project owners could gather related to the nature of the model, which was, not surprisingly, a first order decay model. Moreover, project design in Grobina Polygon was carried out taking into consideration landfilling conditions that were not present once the site started operating. Therefore, a third party was hired to check several factors related to the project, including the gas generation. Unfortunately the only information provided was that the model used was a multi-phased model, as in Maldonado. Although the results of the third-party verification show some future convergence with the original estimates, the increment in yearly gas generation is smaller. Many conclusions can be reached based on this fact alone, but it is reasonable to assume that with better knowledge of the actual operating conditions at the landfill, the third party could have provided a more realistic assumption of the gas potential at the Grobina landfill. Table 1 presents the LFG estimates for Grobina Polygon, the initial and the third parties estimations.

Finally, the Monterrey case, as mentioned earlier, presents an interesting way to account for local conditions when estimating LFG. After using a standard model with its default factors, the Mexican engineers carried out pump tests and also evaluated the radius of influence of certain wells to estimate the amount of gas generated by a certain mass of waste, or the Lo factor.

Having used the pump test results to estimate a k factor that was more likely to represent local conditions, the engineers in Monterrey achieved a model that could prove a valuable tool for analyzing site conditions for LFG exploitation.

Table 1. Initial and re-assessed LFG estimates for Grobina Polygon

Year	Estimation of LFG production/total LFG generation from disposed waste (1.000 Nm ³ /year)*	Estimation of LFG extraction (1.000 Nm ³ /year)**	Estimation of LFG extraction (Nm ³ /hour)**
2002	510		
2003	970		
2004	1380		
2005	1750	174	60
2006	2080	696	80
2007	2380	1281	148
2008	2650	1786	206
2009	2900	2236	258
2010	3140	2648	306
2011	3370	2993	346
2012	3590	3290	380
2013	3800	3549	410
2014		3781	437
2015		3992	462
2016		4188	484
2017		4372	506
2018		4548	526
2019		4697	543
2020		4825	558
2021		4917	569
2022		4988	577
2023		5046	584
2024		5097	589
2025		3330	385

* Original estimates

** Third-party estimates

What sort of conclusion is possible from such different factors and models to estimate LFG from landfill sites? Is there a “better” model? How can we know which model to use? How can local factors be calculated better to achieve more precise data?

Unfortunately, it is impossible to say that there is one best model or that certain techniques are more appropriate than others. If anything is true about estimating LFG, it is that any model carries high uncertainties and thus is likely to be inaccurate. This is no problem as long as engineers account for it when modeling LFG generation. In Bandeirantes, for example, the model seems to have been accurate because the engineers found that considerable methane was escaping through the landfill's surface. Nevertheless, as the engineers' own tests showed, the model may have been very pessimistic, because the LFG may have escaped at rates between 9,400 Nm³/h and 24,000 Nm³/h, while the difference between the model (23,000 Nm³/h) and the real capture (12,000 Nm³/h) was only 9,000 Nm³/h.

The same rationale applies to the Monterrey project, although in opposite conditions. Even after all the tests were carried out to make sure the model's factors were adjusted to the local conditions, the project captured more than 100 percent of the methane anticipated. In light of so many cases of under-performance, some people may see this as a good case of LFG capture. However, super performance in technical terms, strictly speaking, can also be a bad sign, as the project could be generating more electricity or flaring more methane.

Certain measures can be taken to minimize design problems, however, including using qualified technical and engineering teams with extensive knowledge of LFG. The LFG topic is new in the developing world, and there is still a lack of widely available information to better estimate LFG generation in different kinds of landfill operations. Thus technical knowledge is even more important in these countries, as years of experience may provide better judgment in doubtful situations. Another critical factor is knowledge of the landfill site and its operation in detail. As we saw, the case study models tended not to recognize the lack of proper cover and waste compaction, which led to LFG overestimation and thus oversized facilities. Finally, designing a project in modules, in the most cost-effective way, can provide a cushion for the uncertainty that may lie underground. This was clear in the case of Monterrey. After a few years of stable and successful operation, the LFG engineers realized they had enough experience and available LFG to start a second phase in the same landfill. A new power plant is to be built soon, and this phase will be designed under the CDM framework, meaning that carbon credits will be sold in the international market.

3. LFG Plant Operation

The operation of an LFG plant is a complex task for several reasons. Notably, the dynamics of the landfill, whether it is still in operation or closed, play a major role in the uncertainties and variabilities that LFG engineers have to deal with daily. Also, changes in the waste composition, unexpected climate patterns, and reminiscent conditions from a landfill's earlier days make it difficult for engineers to adjust LFG plants to minimal steady state conditions.

The cases presented during the workshop had similar operational set-ups and similar equipment at the disposal of the technicians and engineers responsible. All the projects but one (Grobina Polygon) had individual gas extraction regulation for each of the wells connected to the plants. Moreover, only one of the six cases (Olavarría) did not have staff on site 24 hours for emergency situations, even though all cases had some sort of 24-hour alarm procedure so that technicians and engineers could rush to the sites in case something went wrong. Only Grobina Polygon lacked a system to remove water and condensates from the gas wells or the horizontal pipes. Finally, only Villa Dominico and Maldonado had automatic regulation for the gas extraction.

It is very difficult to judge whether, and how, LFG plant operation may affect plant performance, as many factors play a role in each plant's performance. From the case studies, however, it is possible to draw important recommendations on how to improve the operational profile of an LFG plant. For LFG plants extracting gas from landfills still in operation, the biggest operational challenge is likely to be operating the plant in harmony with ongoing landfilling. Connecting and disconnecting wells to allow landfilling machines and personnel to reach the operations front should be avoided. Broken wells and corrupted pipelines may require civil works maintenance, and a seamless dialogue with the landfill operator will be critical to get the necessary repairs done promptly. Finally, an adequate landfill operation, as seen in this report, is key to a successful LFG operation, and thus the involved parties need to share the goal of best practices in waste landfilling.

The use of adequate and technologically advanced equipment is also a plus in LFG operations. While most of the case studies used the tools necessary to operate their plants successfully, deficiencies were found. The Maldonado project initially suffered from a lack of modulators to regulate the gas flow into the power plant. Sucking more gas than it could actually handle, the power plant had to be shut down several times, with all the LFG sent to the flares. The flares were not designed to handle all the gas they were receiving, creating another problem. Moreover, the project in Maldonado lacked a portable gas analyzer for most of 2006, when the only one available broke down and was sent for repairs outside Uruguay. Without the gas analyzer, it became impossible for the engineers to understand what they were getting from each well and therefore how to regulate the whole plant.

4. Case Study Comparison

The case studies vary significantly in both scale and profile. While some sites had continuous and expert support throughout the project life, others had to handle the issues they faced almost in a learning-by-doing approach. Nevertheless, all cases provide significant lessons for future projects.

Table 2 summarizes the main information provided by all six case studies.

Table 2. Comparison of case studies

	Bandeirantes	Villa Dominico	SIMEPRODESO	Maldonado	Grobina Polygon	Olavarría
Estimated m ³ x 10 ³ LFG/year (2006)	215,000	116,500	15,340	1,963	696	3,408
Real m ³ x 10 ³ LFG/year (2006)	103,000	13,100	31,230	1,496	561	677
Difference m ³ x 10 ³ LFG/year	-112,000	-103,400	+15,890	-467	-135	-2,731
Difference in %	-48 %	-89 %	+104 %	-24 %	-20 %	-80 %
Gas extraction from waste, 10 ³ x tons	20,000	25,000	8,700	335	41	180
Real extraction rate in 2006, m ³ /ton x year (at 50 % CH ₄)	5.15	0.52	3.59	4.47	13.70	2.25
Worldwide range in m ³ /ton x year*	3 – 6 m ³ /ton x year (at 50 % CH ₄)					

*Willumsen, Hans. 2004.

This table yields interesting analyses. The numbers show clearly that, with the exception of Monterrey, all the projects captured less gas than estimated during project design. And to some extent, all the under-performers planned actions to try to improve gas capture, as described below.

1. As mentioned, Bandeirantes is studying the possibility of covering part of the area where gas is extracted to reduce air intrusion and avoid methane escape into the atmosphere. As the Bandeirantes landfill is approaching the end of its active life, a final clay cover will likely help improve the LFG quality and quantity.

2. In Villa Dominico, the LFG operators are considering a drastic reduction in the overall level of leachate at the site to improve gas capture. Although this solution may turn the project around in technical terms, in economic terms things are much more complicated. Extracting and treating all the leachate will require considerable investment at a relatively high risk, as the gas quantity may fall short of expectations. Thus the commercialization of the emission reductions may not be enough to pay back the investment required to install and operate the leachate treatment facilities.

3. Maldonado is considering applying a new cover for the existing extraction area and is improving the overall operation profile (more compaction, better leachate management) of the second cell to allow for more gas production and extraction.

4. Olavarría is ready to invest in new wells and a more impermeable cover to stop the air intrusion problem that has contributed to lower-quality gas extracted.

5. In Grobina Polygon, the situation is problematic because the project is operating in the red. Any new investment possibility is viewed with concern because of the dubious possibility of returns. Nevertheless, the landfill and LFG plant managers are working to have some sort of waste classification prior to landfilling, as well as leachate circulation to create a more

moisturized environment for faster organic decay. Both measures were supposed to be part of the project from its inception but were never implemented.

6. In face of the better-than-expected results, the city of Monterrey is investing heavily in the expansion of its LFG-to-energy facilities. An extra 6 MW of installed capacity will be in place from the beginning of 2008, bringing the site's total electricity generation capacity to about 13 MW and making it one of the largest LFG-to-energy plants in the world.

Another interesting aspect that needs to be analyzed is the LFG, or CH₄, extraction per ton of waste. This analysis is interesting not only because it allows close comparison of projects' performance, but also because it takes into account only the mass of waste where the gas is extracted instead of the whole waste mass in the landfill.

Hans Willumsen¹ carried out a study in 2004 of more than 1,200 LFG plants throughout the world. One of the criteria he looked at was m³ LFG/t waste. His evaluation showed that on average the plants yielded between 3 m³ and 6 m³ of LFG (at 50 percent CH₄) per ton of waste. Table 2 shows that by this criterion, in 2006 three projects performed as expected, two under-performed, and the remainder extracted more gas per ton of waste than one would consider reasonable. This analysis can shed light on the questions posed in the modeling session. Because it can be difficult to say whether the predicted amount of gas exceeds or falls short of what is produced, a comparison of several landfills based on empirical information can provide a more realistic assessment of an LFG project's performance.

Roundtable Discussion

To evaluate the information in the case studies and provide more insight into the issue of modeling vs. results, a panel of LFG specialists was invited to the workshop. The following professionals took part in the panel:

- Susan Thorneloe, Emissions Standard Division, EPA, U.S.A.
- Richard P. Watson, Delaware Solid Waste Authority, U.S.A.
- Jeff Pierce, Vice-President, SCS Engineers, U.S.A.
- Frank Caponi, Supervising Engineer, Sanitation Districts of Los Angeles County, U.S.A.
- Karl-Heinz Pasch, CEO, EnDI AG, Germany
- Carl Bartone, solid waste management specialist and LFG consultant to the World Bank
- Hans Willumsen, solid waste management specialist and LFG consultant to the World Bank

Each of the panelists brought unique opinions on the issues discussed during the workshop. The following aspects of landfill design and operation, as well as LFG modeling and plant operation, were pointed out for further investigation and analysis.

- **Landfill design and operation.** The panelists all agreed that the greatest factor affecting LFG project performance is landfill design and operation. Aspects such as cell depth (less than 10–15 m) and leachate management conditions are usually not reflected during LFG modeling, leading to considerable deviations between theory and practice regarding LFG capture.
- **LFG modeling.** Although it is widely known that choosing the right factors is key to achieving a realistic LFG generation curve, the panelists pointed out a more subtle issue

¹ WILLUMSEN, HANS, LFG Consult, (2004); Landfill gas recovery plants. Looking at types and numbers worldwide. Article in Waste Management World, July-August 2004; published by International Solid Waste Association (ISWA)

related to LFG modeling: how the models are used and applied. Unfortunately, with the boom in the carbon market, many inexperienced engineers have gone out to model LFG generation with little knowledge of waste management and landfill operation. Moreover, with only basic literature on LFG available, less experienced professionals may fail to recognize, and factor in, the main issues affecting LFG modeling. Issues such as well-field expansions are usually not shown in the curves, which often appear too smooth to reflect any real conditions.

- **Water and leachate management.** One of the most critical factors affecting LFG recovery in the case studies presented was leachate. Poor leachate management may affect LFG generation and capture through waste immersion and gas well liquid blockages. Although one of the solutions presented for excess leachate—the installation of individual pumps in gas wells—worked well in Maldonado, it may not work properly in every LFG facility. For instance, the pump may not be able to extract leachate from the well's whole area of influence, and thus the effect on gas extraction may be minimal or nonexistent. The panel's recommendation was a good leachate management system to avoid excess water inside the landfill.
- **Landfill operation and LFG plant operation.** The panel made it clear that the potential conflict between landfills and the LFG plant operators, if they are different entities, needs to be addressed. Simultaneous operations can result in conflict, as the landfill's operation front may be the area where gas production is at its peak. Besides, LFG capture facilities require pipes, manifolds, and other equipment to be installed on the landfill's surface, potentially interfering with the performance of machines and landfill workers. A clear and mutual agreement between the LFG plant and the landfill operators is therefore necessary for successful LFG capture.
- **Pump tests.** According to one of the panel members, pump tests are worthwhile if done over long periods of time. The tests should be seen as an exploratory exercise, allowing for gathering more information about the waste mass, leachate levels, and other landfill characteristics that cannot be inferred from its surface.

Recommendations

As seen from the case studies discussed here, problems exist in all LFG plants. Whether during the design, implementation, or operation stages, issues are likely to arise. To minimize problems in an LFG project, the following measures can be adopted and implemented:

Landfill Operation

1. Adopt efficient waste compaction to eliminate air and thus create adequate conditions for anaerobic decomposition of the organic matter.
2. Allow for a depth of at least 10 m in the landfilled waste before drilling wells and trying to extract the gas. Experience has shown that a depth of less than 10 m means the bottom of the well is too close to the surface and the possibility of air intrusion is significantly increased.
3. Adopt daily waste cover to increase anaerobic decomposition and promote better sanitary conditions in the landfill. Also, adopt final landfill covers with at least 50 cm of clay to seal the landfill, contribute to faster decomposition, and drastically reducing excessive air and water intrusion.
4. Have a good leachate management system in place. While providing moisture to the waste mass, leachate is desirable to accelerate organic decomposition. However, a badly managed leachate system causes excess leachate to stay inside the landfill, clogging the gas wells and impeding gas extraction. It is important, therefore, that the system is able to maintain the leachate inside the landfill at adequate levels.

Modeling

1. To the extent possible, use local parameters. If local parameters are not directly available, try to derive them from default data in specialized literature or from other projects in the same area, adjusting the numbers to local conditions such as weather, landfill engineering, and landfill operation.
2. Adopt multiphase models to account for the different gas potential and decay rates from different kinds of waste.
3. Know the waste type in the landfill, taking samples to measure the waste's carbon content if possible.
4. Take advantage of test pumping if resources are available, making sure that the test lasts longer than 6 weeks. Extrapolate more information from the tests than just LFG-related data. Other useful information includes leachate levels inside the landfill, well conditions, and waste mass accommodation. Use the test pumping procedures to determine the radius of influence of the wells studied and thus calculate the gas potential of a certain mass of waste, as explained in the Monterrey case study analysis.

LFG Plant Construction and Operation

1. Install gas wells of at least 50 cm in diameter and with 150 mm high-density polyethylene perforated pipe PN 10 surrounded by gravel.
2. Be prepared to use individual leachate pumps to extract any liquids that may clog the gas wells and thus impede gas extraction.
3. Install pipelines with a downgrade slope to allow for the gravity extraction of any condensates that may form during LFG extraction.
4. Install more than one blower, flare, and gas engine, if applicable. For example, two smaller scale flares instead of one larger piece of equipment allows for better adjustment of the plant in case the gas extraction varies considerably. The same rationale applies for blower and gas engines.

Conclusions

The International LFG Workshop, carried out by the World Bank and sponsored by CIDA, set a venue for the discussion of LFG project performance around the developing world. Presenting cases from Argentina, Brazil, Latvia, Mexico and Uruguay and bringing specialists with extensive experience in LFG modeling and extraction, the workshop aimed to enhance knowledge about this exciting topic, which is still not well understood topic in developing countries.

Five of the six case studies captured less gas than anticipated during the projects' modeling phases. The following causes of under-performance were pointed out:

- Lack of adequate waste compaction, facilitating air intrusion and aerobic decomposition of waste (most of the cases, including Bandeirantes, Maldonado, and Olavarría)
- Poor leachate management, causing gas wells to become clogged or completely impeding vertical gas extraction (Villa Domínico)
- Waste landfilling procedures different from those anticipated during LFG project design (Grobina Polygon) and lack of basic equipment to adjust LFG extraction and flaring (Maldonado)

- LFG modeling using factors from international literature instead of local values, adding uncertainty to models that provide results with error margins of up to 50 percent

Nevertheless, all these issues can be managed, and most of the projects are studying measures to improve LFG capture. A final and thick clay cover is being studied in both Maldonado and Olavarría. Bandeirantes is considering a polyethylene cover in parts of the landfill to avoid air intrusion and LFG escape to the atmosphere through the landfill surface before the final clay cover is installed. At Grobina Polygon, measures are planned to circulate the leachate into the landfill, increase moisture in the waste mass and accelerate organic decomposition, separate recyclables, and increase the fraction of organic waste landfilled. At Villa Domínico, the various parties involved in the project are discussing measures to extract and treat excess leachate from the landfill, thus allowing increased gas extraction. At Monterrey's landfill, on the other hand, the better-than-expected performance is leading to an expansion of the LFG-to-energy facilities.

Of the several lessons presented in the case studies, the most important is that adequate landfill operations are fundamental to the success of LFG projects. Adequate waste compaction, good leachate management, and adoption of daily waste cover are some of the key factors that can have a significant impact on LFG generation and extraction. Unfortunately, developing countries in general lack adequate waste disposal facilities and adopt poor final waste disposal practices, making LFG projects an even greater challenge than they are to begin with. However, with many countries interested in finding solutions to waste issues, sanitary landfills are likely to slowly become the norm in many emerging and poorer nations. If landfill gas generation in these new sites is seen not as a liability but an asset, landfill engineering and operation will make reasonable and conservative LFG modeling exercises look similar to reality.