

**CASE STUDIES
OF
CDM - LANDFILL GAS PROJECTS
MONTERREY, MEXICO (BENLESA)**

**PRESENTED AT A
WORKSHOP
IN
THE WORLD BANK
19TH APRIL 2007**

CONTENT

1. BACKGROUND	3
1.1. General background	3
2. SITE INFORMATION	4
2.1. Data for Area	4
2.2. Landfill construction	4
2.3. Waste data	5
2.4. Landfill operation	6
3. ESTIMATION OF LANDFILL GAS	6
3.1. Gas Model	6
3.2. LFG estimation	8
4. TEST PUMPING	9
5. REAL LFG EXTRACTION	11
5.1. LFG extracted compared with real extracted	11
6. LANDFILL GAS PLANT	11
6.1. LFG Collection System	11
6.2. Gas Compressor/Pump System	12
6.3. Utilization System	12
6.4. Energy Production	12
6.5. Operation of the LFG Plant	13
6.6. Measuring and analyzing system	13
6.7. Consultant, Contractor and O&M employees	14
6.8. Economy	14

1. BACKGROUND

1.1. General background

Description of SIMEPRODESO Landfill

General Description of Landfill Facilities

The SIMEPRODESO landfill is located in north side of Monterrey, Nuevo Leon in the district of Salinas Victoria. The landfill was established on a greenfield site with a total landfill area of 220 hectares. Since operation began in 1991, the landfill has been accepting mostly non-hazardous domestic and commercial waste as well as some non-hazardous hospital and industrial waste.

The landfill is fenced off with a security patrol. It has no scavengers and is not accessible. The landfill facility is well equipped. The infrastructure includes an administration building, a weigh station for incoming waste, a laboratory, a guard house at the entrance of the facility, a machine and truck maintenance area, a state of the art materials recovery facility, an incinerator (not in operation) and a building for sanitation and gasoline supply.

Fill History

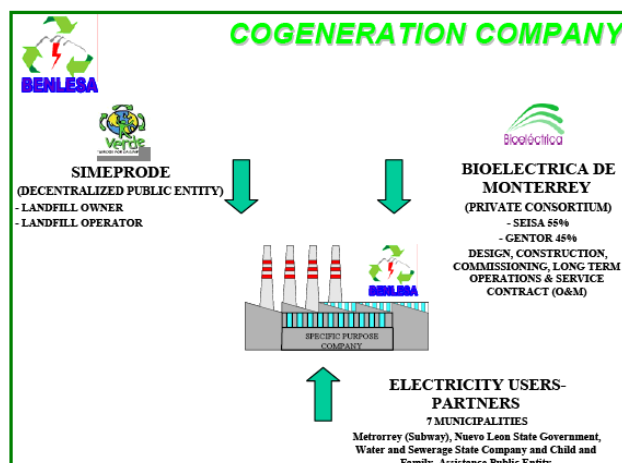
The 44 ha cell from which the biogas will be collected was filled with 7.7 million tons of waste between 1991 to 1999, at which time it was closed and capped with clay. The landfill continues to accept waste and is expanding to fill other cells in the 210 ha site.

Description of LFG Plant (Benlesa)

The Monterrey project is now fully implemented. The power plant has been in operation since May 2003 and has resulted in the destruction of nearly 773,000 tons equivalent of CO₂ (as of January 1, 2007) and the generation of about 194,000 GWh.

The dissemination and training efforts were very successful. When reviewed in the context of the increasing awareness of the urgency and magnitude of the climate challenge, the project in Monterrey has to be recognized for its pioneering design, and results.

In summary, the project has promoted the design, construction and operation of the first ever methane gas power plant in Mexico, and Latin America, that incorporates local and global environmental concerns in its scope and operation. The project is currently powering city lights at night and the Metro system during the day in Monterrey, all of this is being done with landfill gas that would otherwise have been leaked into the atmosphere, contributing to greenhouse gas accumulation. The project has provided the much needed momentum in the efforts to further replicate the concept in the region. At present the project is operating at full capacity, has a positive financial performance, as well as excellent prospects to continue replication of this concept.



2. SITE INFORMATION

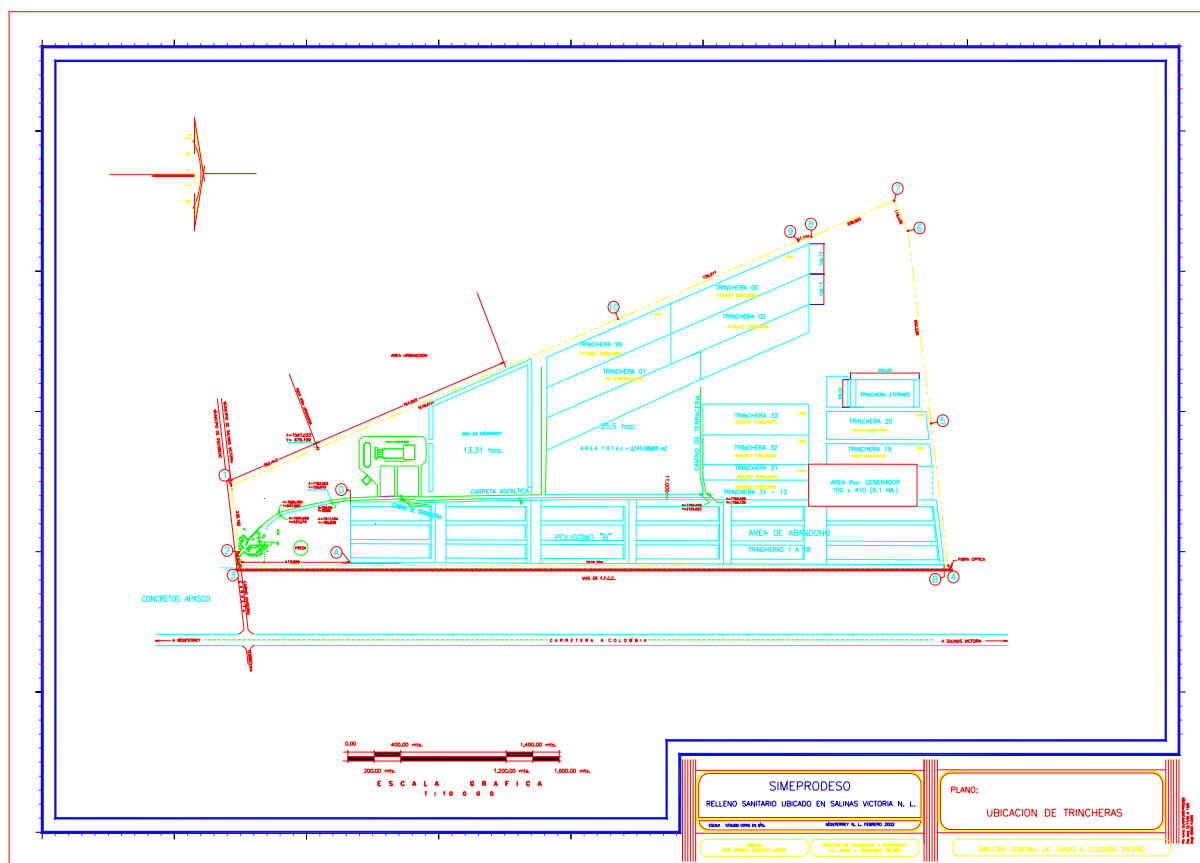
2.1. Data for Area

Please, fill out table 1 below. If necessary give a short description or comments to the site information.

City	Salinas Victoria, N.L.
Name of the landfills	Simeprode Landfill
Site geology (sand, clay, etc.)	Clay
Groundwater over/beneath bottom	Beneath bottom
Precipitation (mm rain water)	470
Normal range of temp. Win./Sum. (°C)	15.9 / 24.9

Table 1: Site area information

Place a plan drawing over the landfill if possible



2.2. Landfill construction

Please, fill out table 2 below. If necessary give a short description or comments to the site information.

Start of landfill (Year)	1990
Closing of landfill (Year/year expected)	2020
Area designated for landfilling (ha)	210

Site capacity at closure (Mio. tons)	35
Area used in 2006 (ha)	105
Max./min. depth of landfill 2006 (m.)	6
Average depth of landfill 2006 (m.)	6
Waste in place 2006 (Mio. tons)	1.5
Gas extraction in 2006 from (Mio. m ³)	31.23
Annual waste quantity (1,000 tons)	1.5
Leachate drainage system (yes/no)	yes
Type of membrane in the bottom (if any)	----

Table 2: Site construction data

2.3. Waste data

Please, describe the possibility for having good or bad historical information about the waste quantity and quality (we know this in many cases is difficult topic). Try to fill out table 3 as shown below with actual data and actual years for your landfill.

Year	MSW (ton)	Industrial/ Commercial (ton)	Other (ton)	Total (ton)
.....				
1990				
1991	518,732	----	----	518,732
1992	732,000	----	----	732,000
1993	988,818	----	----	988,818
1994	812,000	----	----	812,000
1995	824,000	----	----	824,000
1996	850,000	----	----	850,000
1997	714,283	203,822	----	918,105
1998	708,904	219,491	1,612	930,007
1999	796,344	347,921	11,581	1,155,846
2000	943,859	391,136	87,545	1,422,540
2001	1,008,976	289,948	54,312	1,353,236
2002	1,079,671	369,016	85,362	1,534,049
2003	1,123,601	385,936	83,787	1,593,324
2004	1,179,417	378,607	96,500	1,654,524
2005	1,116,329	399,566	66,623	1,582,518
2006	1,137,469	387,631	49,627	1,574,727
.....				
.....				
Total:	14,534,403	3,373,074	536,949	18,444,426

Table 3: Amount of waste disposed of.

In table 3 the overall waste composition is divided. If more detail is available please, describe this by filling out table 4 below (with more or less breakdown, depending on the availability)

Type of waste	Waste composition (% by weight)
Domestic	68.89

Industrial, Commercial & Institutional	23.70
Construction	2.87
Garden waste	4.09
.....	
Other	0.45
Total:	100.00
Total organic (if this is available)	66.49

Table 4: Waste composition

2.4. Landfill operation

Please, describe further information on landfill operation and fill out table 5. Explain very brief the leachate collection system.

Usage of compactor (yes/no)	yes
Number of compactors	2
Is temporary cover used (yes/no)	yes
Frequency of temporary cover	daily
Existence of final cover (yes/no)	yes
Type and thickness of final cover	30 cm.
Leachate collection from the bottom (yes/no)	yes
Leachate collection from trenches (yes/no)	yes

Table 5: Landfill operation

3. ESTIMATION OF LANDFILL GAS

3.1. Gas Model

LFG production was estimated using a model developed by the USEPA referred to as "USEPA E-PLUS".

The model is shown below:

$$Q_{T,X} = kR_x L_o e^{-k(T-X)}$$

$Q_{T,X}$ = flow of methane gas in year T for waste deposited in year X (m³/yr)

X = year waste was added to landfill

T = current year

L_o = methane gas generation potential (m³/ton waste)

k = methane gas generation constant (1/yr)

R_x = the total residue deposited in year X

Parameter Estimation

Among the most important parameters in this model are the methane gas generation constant (k) and the methane gas generation potential (L_o). L_o was estimated using typical values from operating US LFG projects and adjusting for differences in the composition of the SIMEPRODESO waste. k was estimated by measuring the methane gas production on site and using the USEPA E-PLUS model equation to solve for k.

The methane gas generation potential (L_o)

Using flow data from operating U.S. LFG projects, a relationship between apparent values of L_o and annual precipitation was determined. Based on this relationship and the annual precipitation in Monterrey, an L_o of 134 m³/Mg was estimated.

This L_0 was then adjusted to account for the higher food content and thus higher moisture content of Mexican waste relative to US waste. This was done using the measured food waste content at the SIMEPRODESO landfill (38%) and typical food content and moisture content values of US waste (25% moisture content and 6.7% food content). It was also assumed that food waste has a moisture content of 70%. Given this data and assumption, the larger food waste content at the SIMEPRODESO landfill increases the waste moisture content from 25% to 46.6%. This increased moisture content reduces the L_0 value from 134 m^3/Mg (for the US-based estimate) to 95.4 m^3/Mg (for the SIMEPRODESO waste).

The methane gas generation constant (k)

A pump test was conducted at a representative location in the closed 44 ha cell of the SIMEPRODESO landfill (see picture on following page) and the data were analyzed using the USEPA Method 2E in order to estimate k.

The approach was as follows:

- Landfill gas was extracted from a test well at a rate equal to the production of the LFG (i.e. the steady state flow rate) and the influence of the well extraction was measured by the change in pressure at monitoring probes installed at various distances from the extraction well. The radius of influence of the well and thus the area around the well from which gas could be extracted was then estimated from these measurements.
- Based on the landfill depth and the radius of influence, the volume of waste influenced (i.e. the volume contributing gas to the well) was then calculated.

The corresponding waste mass (R_w) is then determined by multiplying the volume of waste by the estimated waste density.

- As the rate of gas extraction equaled the rate of gas production; the measured steady state flow rate could be taken as the rate of LFG production. In order to determine the rate of methane production, this number was multiplied by 0.5 to account for the 50% methane content of LFG. This flow rate was then related to the waste mass, average age and L_0 using the USEPA E-PLUS model equation in order to solve for k.

Based on the data from the SIMEPRODESO landfill, the radius of influence of the well was estimated to be 38 meters. The pump test also indicated the gas flows were unimpeded by any barriers such as the clay filling used in landfilling. The LFG generation constant was calculated using the USEPA E-PLUS equation (above) and the following parameters:

Parameters used in USEPA Method 2E to estimate the LFG generation constant (k)		
Parameter	Value	Basis
waste depth	22 meters	SIMEPRODESO data
radius of influence of well	38 meters	field pump test
steady state flow	1.736 m^3/min	field pump test
average waste age	5 years	SIMEPRODESO data
waste density	0.71 Mg/m^3	typical value for 'in place' waste
methane gas generation potential (L_0)	95.4 m^3/Mg	estimated as described above

The LFG generation constant (k) was found to be 0.0606/yr. This corresponded with a recommended value (0.066 /yr) that was developed based on previous studies and adapted to the Monterrey conditions. Since the variables of the pump test program can be interpreted in different ways, the test results were considered to be confirmation of the recommended k value (0.066/yr), which was used for the model estimation of the gas production. The rest of the parameters used in the LFG production model are shown in the following table.

Input parameters for model used to estimate gas production at the SIMEPRODESO landfill.		
Parameter	Value	Basis
Methane gas generation constant (k)	0.066/yr	Precipitation-based value increased to account for highly degradable food waste. The value was consistent with that found from a 'pump test' at the site (0.0606/yr). The pump test was able to estimate the methane production rate by determining the rate of methane extraction (by the pump) necessary to balance the rate of methane production (by the portion of the waste that methane was extracted from). (see detailed description above)
Waste methane gas generation potential (Lo)	95.4 m ³ CH ₄ /Mg waste	Estimated based on value of US waste accounting for the differences in moisture content resulting from the higher waste food content in the SIMEPRODESO landfill. (see detailed description above)
Waste cell area	44 ha	SIMEPRODESO data.
Waste depth	22 meters	SIMEPRODESO data.
Waste density	0.71 Mg/m ³	Typical value for 'in place' waste.
Waste age (year 2000)	5 years average	SIMEPRODESO fill history.
Concentration of methane in LFG	50%	Typical value confirmed by measurement at site (actual measurements ranged from 50-60%).

3.2. LFG estimation

Please, inform about the result of the estimation by filling out table 6

Year	Estimation of LFG production (1.000 Nm ³ /year)	Estimation of LFG extraction (1.000 Nm ³ /year)	Estimation of LFG extraction (Nm ³ /hour)
.....			
2000	----	----	
2001	----	----	
2002	28,550	19,990	2,282
2003	26,710	18,700	2,135
2004	25,020	17,510	1,999
2005	23,420	16,390	1,871
2006	21,920	15,340	1,751
2007	20,500	14,350	1,638
2008	19,200	13,440	1,534
2009	17,980	12,590	1,437
2010	16,820	11,770	1,343
2012	15,750	11,030	1,259

Table 6: Estimation of LFG production and extraction

Estimated Methane Production (top line) and Capture (bottom line) Over the Lifetime of the Project

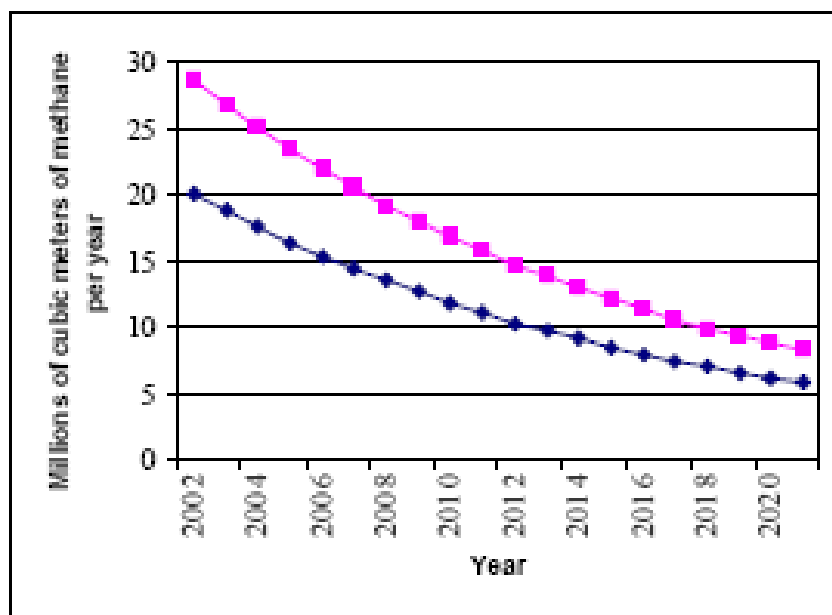


Figure 1: Estimation for gas extraction

The model predicted that, over the lifetime of the project, 313 million m₃ of methane will be produced by the landfill. Of that 214 million m₃ of methane, equivalent to 858,000 tC, will be captured by the LFG collection system.

4. TEST PUMPING

If a test pumping is carried out, please give some information about this and fill out table 7

Pump capacity (m ³ /h)	----
Number of test wells	1
Duration of the test pumping	7 days
Gas extraction from well no.1 (m ³ /h)	1300
Gas extraction from well no.2 (m ³ /h)	----
Gas extraction from well no.3 (m ³ /h)	----
Gas extraction from well no.4 (m ³ /h)	----
.....	
Total gas extraction (m ³ /h)	1300

Table 7: Data and results from the test pumping

The available gas composition can be filled in to table 8 below

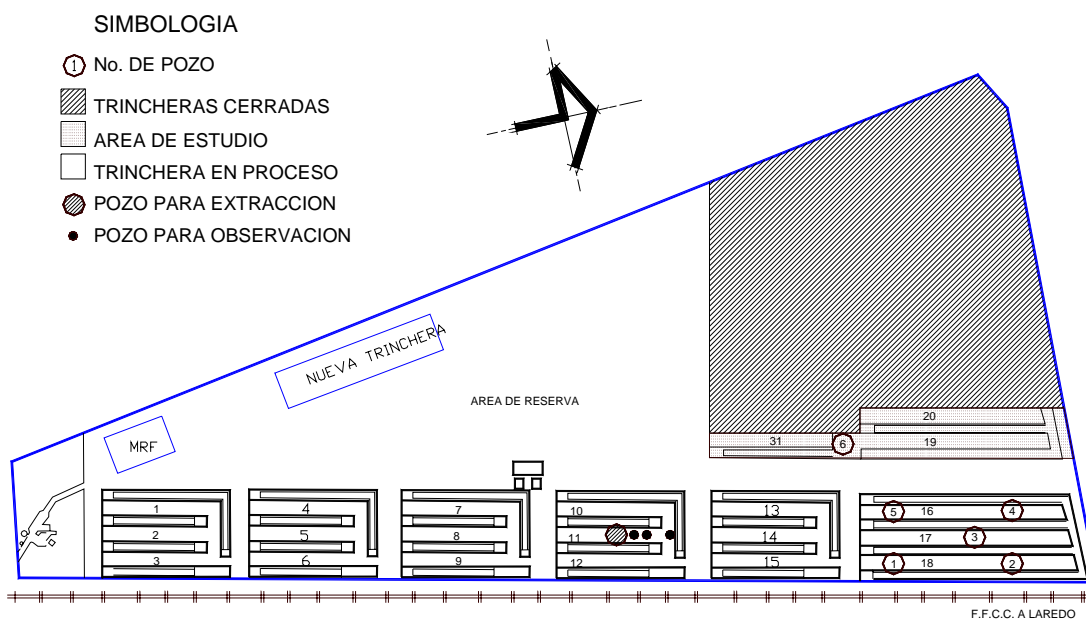
Well No	CH ₄ %	CO ₂ %	O ₂ %	N ₂ %
1	54.90	40.53	0.81	3.53
2	----	----	----	----

3	----	----	----	----
4	----	----	----	----
.....				
Total	54.90	40.53	0.81	3.53

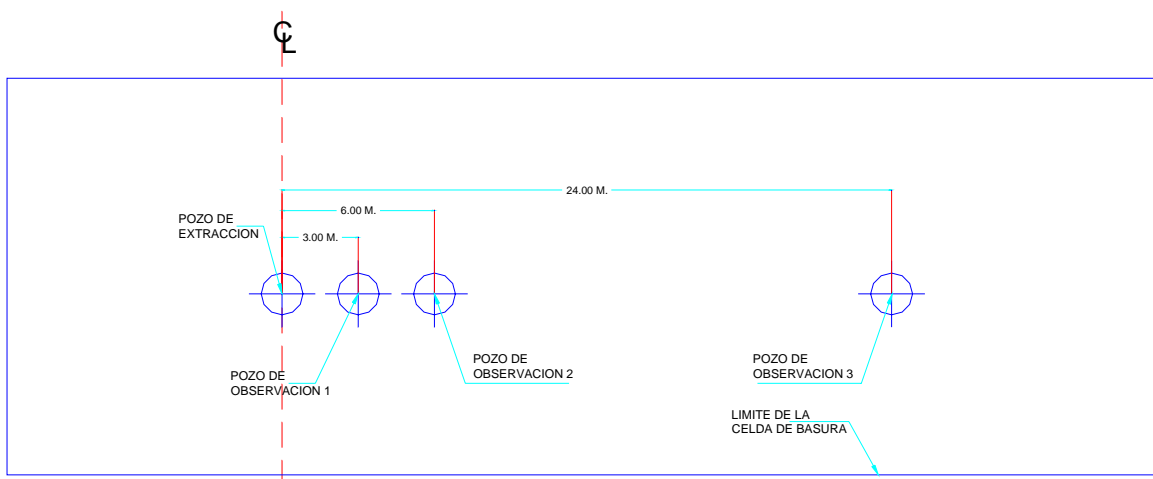
Table 8: LFG composition from test pumping

If a plan drawing for the test wells at the landfill is available place it as the example below.

ARREGLO DE POZOS PARA LA PRUEBA DE PRODUCCION DE BIOGAS



DETALLE DE ARREGLO DE POZOS PARA PRUEBA DE PRODUCCION DE BIOGAS



Inform if the results from the test pumping were valuable, when the size of the LFG plant was decided. Was the result comparable with the result from the model?

5. REAL LFG EXTRACTION

5.1. Estimated LFG extracted compared with real extracted

Compare the estimated gas extraction from table 6 with the real extraction in table 9 below:

Year	Estimation of LFG extraction (1.000 Nm ³ /year)	Real LFG extraction (1.000 Nm ³ /year)	Difference (+/- 1.000 Nm ³ /year)	Difference (+/- %)
.....				
2000	----	----		
2001	----	----		
2002	19.99	----	-19.99	-100%
2003	18.70	19.41	00.71	3.79%
2004	17.51	33.26	15.75	89.94%
2005	16.39	32.81	16.42	100.18%
2006	15.34	31.23	15.89	103.58%

Table 9: Estimation of LFG production and extraction

5.2. Estimated LFG composition compared with real composition

Compare the estimated gas quality used in the original calculation with the real annual average quality in table 10 below (if all the mentioned gasses are not available, the important is of course the methane concentration):

Year	Estimated gas quality				Real gas quality			
	CH ₄ %	CO ₂ %	O ₂ %	N ₂ %	CH ₄ %	CO ₂ %	O ₂ %	N ₂ %
.....								
2000	50	50	0	0	----	----	----	----
2001	50	50	0	0	----	----	----	----
2002	50	50	0	0	----	----	----	----
2003	50	50	0	0	----	----	----	----
2004	50	50	0	0	48.60	35.60	2.30	13.50
2005	50	50	0	0	52.19	39.10	2.00	6.71
2006	50	50	0	0	52.24	40.2	2.78	4.78
Actual								

Table 10: Estimation of LFG production and extraction

6. LANDFILL GAS PLANT

6.1. LFG Collection System

Please, indicate the drilling system, how the wells are constructed and/or (if carried out) the horizontal collection system. Fill out table 11 below

Wells	
Number of wells	248
Depth of wells/average depth (m)	19
Diameter of well (mm)	300

Diameter of gas extraction pipe (mm)	125
Distance between wells (m)	30
Presence of water/condensate in wells (yes/no)	yes
Water/condensate pump in wells (yes/no)	no
Horizontal gas extraction pipes	
Horizontal gas extraction pipes (total m)	17,600
Diameter of horizontal gas extraction pipe (mm)	63
Presence of water/condensate in pipes (yes/no)	yes
Water/condensate removal system for pipes (yes/no)	no
Horizontal gas collection system (from wells to gas pump)	
Diameter of horizontal collection system (mm)	315 (2 systems)
Condensate trap at low points (yes/no)	yes

Table 11: LFG Collection system

6.2. Gas Compressor/Pump System

Please, fill in table 12 below

Type of gas compressor/pump	Vacuum pump
Capacity of gas compressor/pump (m ³ /hour)	2,500
Suction pressure at the pump (mbar)	400
Suction pressure at the wells (mbar)	50

Table 12: Gas compressor/pump system

6.3. Utilization System

Please, inform very brief about the utilization system and fill in table 13 below

Flare	
Type of Flare (open or closed)	open
Number of flares	3
Total capacity of flares (m ³ /h)	5,000
Actual gas used in flare (m ³ /h)	0
Gas Engine/generator unit(s)	
Fabricate and type of gas engine	GE-Jenbacher
Number of engines	7
Power production/generator (kW)	1,060
Actual total electricity production (kW)	7,420
Boiler or other utilization system	
Total boiler capacity (kW)	----
Actual total heat production (kW)	----

Table 13: LFG utilization system

6.4. Energy Production

Please, fill in table 14 with the yearly energy production

Year	Electricity production (MWh/year)	Heat production (MW/year)
.....	----	----
2000	----	----
2001	----	----
2002	----	----
2003	32,373	----
2004	55,429	----
2005	54,703	----
2006	52,104	----

Table 14: Annual Energy production

6.5. Operation of the LFG Plant

Please, describe briefly the operation of the plant, especially the problems. If there is any automatic regulation for the gas extraction system, please describe that too. Then fill out table 14 below.

Is it possible to regulate the suction/flow from the individual wells and/or horizontal extraction pipes (yes/no)	yes
Are there any automatic regulation for the gas extraction (yes/no)	no
Is water/condensate from gas wells and/or horizontal extraction pipes removed (yes/no)	yes
Are there operation staff at the plant 24 hours/day	yes
Do the alarm system call for attention 24 hours/day to the operator (yes/no)	yes
What is the plant efficiency (working hours/year)	7,577

Table 15: Operation of the LFG Plant

6.6. Measuring and analyzing system

Please, inform briefly about the measuring and analyzing system and fill in table 16 below.

Are there stationary gas analyser in the plant (yes/no)	no
Which gases are analysed (CH ₄ , CO ₂ , O ₂ , H ₂ S, ?)	----
Type of portable gas analyser used	GA2000
Which gases are analysed (CH ₄ , CO ₂ , O ₂ , H ₂ S, ?)	CH ₄ , CO ₂ , O ₂
How often is the gas analysed from the individual wells (daily, weekly, or ?)	daily
Are pressure, temperature, etc. measured automatically or manual (a/m)	m

Table 16: Measuring and analyzing system

6.7. Consultant, Contractor and O&M employees

Please, inform briefly about the establishment of the LFG plant, the commissioning, start-up and running-in; was it satisfactory? Was the training of the Operation and Maintenance (O&M) employees satisfactory? Fill in table 17 below

Consultant for implementation (good/poor)	good
Did the consultant have good references and long experience in LFG plants (approx. years)	10
Contractor for implementation (good/poor)	good
Did the contractor have good references and long experience in LFG plants (approx. number of plants)	15
Did the team for start-up and running-in have expertise (yes/no)	yes
Good training of O&M employees (yes/no)	yes
Good O&M manuals (yes/no)	yes

Table 17: Consultant, contractors and O&M employees

6.8. Economy

Please, fill in to table 18 the investment costs and the annual income as well as the annual O&M costs

Year	Investment costs US\$	Annual income from energy US\$	Annual income from CO ₂ credit US\$	O&M costs US\$
.....				
2000	----	----	----	----
2001	----	----	----	----
2002	\$5,400,000	----	----	----
2003	\$5,400,000	\$283,139	----	\$48,636
2004	----	\$3,684,684	----	\$905,100
2005	----	\$4,391,748	----	\$1,320,011
2006	----	\$4,537,606	----	\$1,341,993

Table 18: Economy