THE CITY OF CALGARY'S
LANDFILL GAS AND RENEWABLE ENERGY ASSESSMENT

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ABSTRACT

The City of Calgary, Waste & Recycling Services (W&RS) is committed to reducing Greenhouse Gas (GHG) emissions, protecting the environment, and ensuring public welfare through sustainable development. In keeping with this mission and vision, W&RS formed a private/public partnership for a landfill gas (LFG) assessment.

In June 2001, W&RS, ENMAX, PanCanadian Energy (now EnCana Corporation), and the Federation of Canadian Municipalities (FCM) entered into an agreement to conduct a feasibility assessment for the collection and potential utilization of LFG at the Spy Hill, East Calgary, and Shepard landfill sites in Calgary. The agreement also includes a renewable energy assessment (wind and/or solar power) at the landfill sites. In August 2001, CH2M HILL was retained by W&RS to conduct the LFG feasibility assessment, and Phoenix Engineering Ltd. was retained to complete the renewable assessment.

This LFG assessment is the first step of a multiphase, multiyear project to mitigate GHG emissions from the City's active landfill sites. The study involves LFG generation modeling, on-site LFG recovery testing, and evaluation of a microturbine operating on LFG at one of the test sites. The feasibility assessment commenced in September 2001 and is scheduled to be completed in July, 2002.

This paper discusses: 1) background information for each of the landfill sites, including variations in waste compositions, landfill sizes, relative moisture contents and their effects on LFG generation; 2) variations between predicted and actual LFG recovery, including key issues influencing LFG recovery; 3) preliminary performance summary of a Capstone 330 microturbine operating on recovered LFG from one the landfill sites; 4) other potential LFG utilization technologies; and 5) renewable energy options.

BACKGROUND

The City of Calgary, Waste & Recycling Services (W&RS) currently operates three landfill sites within its city limits, namely the Spyhill, East Calgary, and Shepard landfills, as shown in Figure 1.

The Spyhill landfill (District 1) is located in the northwest quadrant of the city and only accepts residential and commercial wastes. The site occupies approximately 260 hectares (640 acres) of licensed landfill area and 80 hectares (200 acres) of future landfill. Landfilling has occurred at this site since 1968 and is expected to continue to 2041, based on current disposal rates. To date, approximately 3.95 million tonnes of waste have been disposed of at the Spyhill landfill.

The East Calgary landfill (District 2) is located on the east side of the city and accepts residential and commercial wastes only. Until 2000, the East Calgary landfill also

TABLE 1. CITY OF CALGARY 2001 LANDFILL WASTE DISPOSAL VOLUMES[1]

Site	Residential Hand Collection	Residential Container Collection	I.C.I.	Dry Rubble	Total Waste	Clean Fill
Spyhill	67	4	85	9	165	11
East Calgary	72	16	180	14	282	289
Shepard	58	6	142	87	293	172
TOTAL	**197**	**26**	**407**	**110**	**740**	**472**

1. All values are in thousands of tonnes.

operated an industrial waste disposal area, including oil/water separation, asbestos and sulphur/lime disposal, and industrial waste storage. The site occupies approximately 315 hectares (780 acres) of licensed landfill area and 200 hectares (500 acres) of future landfill. Landfilling has occurred at the East Calgary Landfill since 1968 and is expected to continue to 2041. To date, approximately 4.23 million tonnes of waste have been disposed of at the East Calgary landfill.

The Shepard landfill (District 3) is located in the southeast quadrant of the city and accepts residential, commercial and industrial wastes and, since the closure of the industrial waste facility at the East Calgary landfill in 2000, industrial wastes. The site occupies approximately 390 hectares (960 acres) of licensed landfill area and 65 hectares (160 acres) of future landfill. Landfilling has occurred at the Shepard landfill since 1972 and is expected to continue to 2038. To date, approximately 6.85 million tonnes of waste have been disposed of at the Shepard landfill.

In 2001, W&RS was responsible for the disposal of 740,000 tonnes of landfilled waste (excluding clean fill), as shown in Table 1.

Further to the Kyoto Conference in December 1997, the City of Calgary developed a Carbon Dioxide Emissions Abatement Action Plan concerning the abatement of greenhouse gas (GHG). The Action Plan identified W&RS as the largest contributor to the City's carbon dioxide (CO_2) inventory, based on GHG emissions from its three landfills, which accounts for over 30 percent of the corporation's total GHG emissions.

Typical landfill gas (LFG) is comprised of approximately 50 percent methane (CH_4) and 50 percent carbon dioxide (CO_2), with other minor constituents present. Since it is recognized that CH_4 has a much higher impact (global warming potential) on the environment than CO_2, it was in the City's best interest to evaluate the total GHG potential generation rates and quantify GHG emissions from the landfill sites. W&RS also recognized the potential for utilizing the methane component of the landfill gas as an energy source while at the same time dramatically reducing the City's total GHG emissions.

From August 1998 to April 2001, W&RS retained the services of Hetech (formerly Heath Consultants Limited) to evaluate surficial methane concentrations at each of the City's landfills. From September 1998 to May 2001, the Emissions Research and Measurement Division (ERMD) of Environment Canada was retained to assess and quantify GHG from the three landfills based on the preliminary survey information provided by Hetech.

In the spring of 2001, W&RS signed a partnership agreement with ENMAX Corporation (ENMAX) and PanCanadian Energy Ltd. [now EnCana Corporation (EnCana)] to assess the landfill gas collection and utilization potential at the three active landfill sites. In the summer of 2001, the partnership successfully obtained further financial sponsorship for the landfill gas assessment from the Federation of Canadian Municipalities (FCM). On behalf of its project partners, W&RS retained the services of CH2M Hill Canada Ltd. (CH2M HILL) in August 2001 to assess the quantity and quality of landfill gas potential from each of the three landfill sites. CH2M HILL's scope of work involved: 1) conducting preliminary LFG modeling of all three sites; 2) testing on-site LFG production from test wells drilled at each landfill site using a temporary blower and gas incineration system; and 3) evaluating a Capstone microturbine as a potential utilization technology for landfill gas to energy.

LANDFILL GAS MODELING

In Stage 1 of the LFG assessment, CH2M HILL completed computer-based LFG modeling for each of the three active landfills. To ensure that this modeling would be accurate, a formidable amount of data was compiled and analyzed, including annual disposal tonnages from 1976 to the present and recently completed waste composition reports. From this information, CH2M HILL forecasted the annual disposal tonnages up to the completion of each landfill.

TABLE 2: ORGANIC FRACTIONS OF WASTE

City of Calgary Landfill	Organic Fraction (RD + MD fraction)	Readily Decomposable Organic Fraction (RD fraction)	Moderately Decomposable Organic Fraction (MD fraction)
East Calgary	0.71	0.41	0.58
Shepard	0.56	0.45	0.54
Spyhill	0.75	0.47	0.52

TABLE 3: LFG GENERATION POTENTIALS

		Estimated 2001 LFG Generation Potential (cfm)		
Landfill	**Waste Disposed (millions tonnes)**	**LFGGEN Model**	**LandGEM Model**	**Difference (%)**
East Calgary	6.85	2,241	1,856	17%
Shepard	4.23	1,120	973	13%
Spyhill	3.95	1,405	1,151	18%

Note: The above quantities do not include clean fill.

Waste Composition and Moisture Content

Two important factors in determining the total amount and rate of LFG generation from a unit mass of MSW are the weight fraction of the waste that is organic and the moisture content of the waste mass.

Recent City of Calgary studies, 1999 Residential Waste Study and the ICI/CRD Waste Composition Study, allowed site-specific organic content to be determined for each landfill. The organic fraction, which is further broken down into readily decomposable organic fraction (e.g. food and yard waste) and moderately decomposable organic fraction (e.g. paper, cardboard, wood waste), for each landfill is provided in Table 2.

The anaerobic organisms that produce LFG function most prolifically in an aqueous environment; thus, the peak rate of the LFG production and the rate of increase in LFG production are assumed to vary in direct proportion to the moisture content of the wastes. Due to Calgary's dry climate, the moisture content for the East Calgary, Shepard, and Spyhill landfills is assumed to be very low and is taken as 15 percent.

LFG Generation Models

The estimation of LFG production for each site was completed using two separate LFG generation models: the CH2M HILL LFG generation model (LFGGEN) and the USEPA Landfill Gas Emissions Model (LandGEM, version 2.01).

Results of the LFG modeling curves for the three landfill sites are presented in Figures 2 and 3. The models will be adjusted in the future to reflect actual LFG production testing results for each landfill site.

Using the LFGGEN and LandGEM models with the above model inputs, the current (year 2001) estimated total LFG generation potentials for each landfill site are summarized in Table 3.

Both LFG generation models agree that East Calgary has the highest potential for LFG generation and Shepard has the lowest. The LFG potential at Shepard is lower based on the higher volume of C&D waste accepted and landfilled at the site. The generation potential difference is well within the deviation of values that is expected between LFG models used.

The actual generation will vary depending on actual site conditions, landfill properties, waste characteristics, moisture availability, landfill structure, etc. These LFG curves will be adjusted based on the LFG field production testing.

TABLE 4: STATIC TESTING GAS COMPOSITIONS

Landfill	% CH_4	% CO_2
East Calgary	55	38
Spyhill	55	43
Shepard	58	42

LANDFILL GAS FIELD PRODUCTION TESTING

In Stage 2 of the LFG assessment (commencing September, 2001), a number of small diameter survey boreholes were drilled at various pre-determined locations on the landfill site. The wells were used to assess the site cover thickness, grade of waste stream decomposition, refuse moisture, leachate levels, and general sub-grade characteristics. The results from the survey boreholes were evaluated and, if one had not already been predetermined, a testing location was chosen at each site.

LFG field testing began in East Calgary on October 22, on November 19 at Spyhill, and during the first week of January, 2002 at Shepard.

A cluster configuration of three LFG recovery test wells (260 mm diameter borehole) and seven gas probes (102 mm diameter boreholes) was drilled into each landfill and completed in accordance with the test well spacing to a maximum of 50, 75, and 100 metres and to depths ranging between 10 to 15 metres, as depicted in Figure 4. The test wells were completed and equipped with a wellhead, monitoring ports, and valves (Figure 5). The test probes were completed and equipped with a cap and pressure monitoring port.

The three LFG test wells were connected at surface via 100 mm diameter PVC piping to a common manifold. The LFG recovered from the test wells was extracted along a common header using a rotary lobe blower, then routed to a high-efficiency enclosed incinerator for thermal destruction, as represented in Figure 6. All collection piping was sloped to provide for condensate removal.

The LFG testing program consisted of initial static pressure testing, individual well induced flow testing, and composite (combined) well testing. The wells were routinely monitored for parameters such as gas flow rate, composition, temperature, pressure, and trace contaminant concentrations: Volatile Organic Compounds (VOCs), sulphur compounds, moisture content, and siloxanes. The LFG pressure monitoring probes near the wells were monitored for changes in pressure to determine the radius of influence of each of the gas extraction wells. A combined field team from CH2M HILL and W&RS field staff was responsible for data collection throughout the field program.

Initial static testing (passive testing) at the three landfills yielded very low LFG generation pressures measured over time within the landfill waste mass. Increases in barometric pressures would cause decreases in actual gauge pressure measurements, while decreases in site barometric pressures would result in increases in gauge pressure readings, which is a typical occurrence in MSW landfill sites. Initial LFG compositions were as shown in Table 4.

Induced flow testing commenced on November 7, 2001 at East Calgary, on November 22, 2001 at Spyhill, and on January 8, 2002 at Shepard.

TABLE 5: INDUCED PRODUCTION FLOW TESTING AT EAST CALGARY LANDFILL

Individual Well Testing					Combined Well Testing			
Well	**Vol ft^3**	**Ave Rate scfm**	**CH_4 % by Vol.**	**CO_2 % by Vol.**	**Vol ft^3**	**Ave Rate scfm**	**CH_4 % by Vol.**	**CO_2 % by Vol.**
TW1	856,795	47	55.5	41.5	1,623,451	16	54.5	40.8
TW2	711,435	57	51.5	41.5	1,522,111	15	51.7	41.3
TW3	880,162	56	56.1	41.0	2,013894	20	56.4	42.1
TOTAL	**2,448,392**	**53**			**5,159,456**	**50**	**54.0**	**40.1**

TABLE 6: INDUCED PRODUCTION FLOW TESTING AT SPYHILL LANDFILL

			Individual Well Testing			Combined Well Testing		
Well	**Vol ft^3**	**Ave Rate scfm**	**CH_4 % by Vol.**	**CO_2 % by Vol.**	**Vol ft^3**	**Ave Rate scfm**	**CH_4 % by Vol.**	**CO_2 % by Vol.**
TW1	453,137	55	50.0	43.8	0	0	-	-
TW2	480,452	43	47.5	47.1	1,163,678	43	50.6	49.4
TW3					1,401,563	36	50.8	50.6
TOTAL	**933,589**	**50**			**2,565,241**	**79**	**50.7**	**50.0**

East Calgary Induced Flow Testing

Individual well testing ran from November until December 12, 2001 at East Calgary, and combined well testing ran from January 7 to March 22, 2002. The results of the East Calgary induced flow testing are shown in Table 5.

The overall tonnage represented in the zone of influence is 152,424 tonnes. LFG recovery extrapolated over the combined waste mass is estimated at 548 cfm (930 m^3/h). Because the majority of the long-term test data was collected over the winter months with a frozen upper cap, which would result in a higher LFG collection efficiency, the actual LFG recovery will be less than estimated.

Using the CH2M HILL LFG generation model, the 2002 LFG generation estimate for the area tested equalled 627 cfm. In the initial LFG modeling for East Calgary, the LFG recovery using a very low waste moisture content (15 percent) was approximately 87 percent of the predicted LFG generation rate.

For typical MSW landfill sites not incorporating a flexible membrane liner within the final cover, a 70 percent LFG recovery factor can generally be assumed. Seventeen percent of the recovered LFG from the testing phase has been attributed to positive error in the determination of the radius of influence as well as the frozen cap conditions. Therefore, the recovery from the testing phase equals the 70 percent recovery of the predicted CH2M HILL LFG model.

Spyhill Induced Flow Testing

At Spyhill, individual well testing commenced November 22, 2001, with the initial LFG recovery from testwells TW1 and TW2 running from November 22 to December 15. Both wells exhibited signs of air ingression over a short, active testing interval. TW2 and TW3 were used for combined flow testing from January 7 to February 21, 2002. TW1 was not brought on line during this time frame. The results of flow testing for Spyhill are shown in Table 6.

Because of the minimal and equalized movement in static pressure probe readings recorded, pressure influence was difficult to evaluate during the composite well testing. However, it was evident during the active testing phase that the area was easily overdrawn, resulting in air ingression through specific gas migration pathways. The overall tonnage of waste represented in the zone of influence equates to 123,391 tonnes, and the LFG recovery is estimated at 698 cfm (1,186 m^3/h).

TABLE 7: INDUCED PRODUCTION FLOW TESTING AT SHEPARD LANDFILL

	Individual Well Testing				Combined Well Testing			
Well	Vol ft^3	Ave Rate scfm	CH_4 % by Vol.	CO_2 % by Vol.	Vol ft^3	Ave Rate scfm	CH_4 % by Vol.	CO_2 % by Vol.
TW1	722,854	53	60.1	37.4	2,216,400	30	51.3	40.5
TW2	-	-	-	-	1,400,134	20	60.1	39.7
TW3	220,992	42	37.9	30.2	-	-	-	-
TOTAL	**943,846**	**48**			**3,616,534**	**50**	**52.0**	**39.4**

This estimated LFG recovery rate is approximately twice as high as the LFG generation rate estimated using the CH2M HILL LFG model for this section of the landfill (350 cfm or 594 m^3/h). The radius of influence may be higher than what has been observed in the data at the flow rate measured, resulting in higher than predicted LFG recovery. Moisture contents may also be higher than predicted, and a frozen landfill cap would positively influence LFG production testing.

<u>Shepard Induced Flow Testing</u>

Induced flow testing began with TW1 at the Shepard Landfill site on January 8, 2002. TW3 was brought on-line on January 22 and was only operated for a three-day period because of excessive air ingression. TW2 was brought on line in conjunction with TW1, and both were put into operation on February 11, 2002. The results of flow testing for Spyhill are shown in Table 7.

The overall data yields higher than expected results for such a shallow area. TW1 is actually the stronger of the two test wells, with greater LFG generation and recovery; TW2 exhibited signs of air ingression at higher vacuum pressures and flow rates. The overall tonnage represented in the zone (radius) of influence equates to 79,842 tonnes, and LFG recovery is estimated at 1,165 cfm (1,980 m^3/h) extrapolated over the waste mass of the specific landfill section being tested.

This estimated LFG recovery rate is approximately twice as high as the LFG generation rate estimated using the CH2M HILL LFG model for this section of the landfill, which yielded 532 cfm or 904 m^3/h for the section of the landfill being testing. Based on the shallow depth of waste, type of waste, and moisture content, this field-measured LFG recovery rate is extremely high and is possibly attributable to a higher than observed radius of influence.

The Shepard LFG test system will remain online for an eight-week period starting in late April, as it will be used to supply LFG to a trailer-mounted microturbine power system. Landfill gas flow rates will be reduced and adjusted to represent sustainable LFG recovery, and the LFG generation curve will be adjusted based on final data recovery and assessment.

<u>Landfill Gas Contaminants</u>

The overall concentration of trace contaminants, including siloxanes, in the LFG measured at all three landfill sites is generally low. Additional lab testing is currently underway, and more comprehensive results are pending.

Emission data from the incinerator stacks, as well as the microturbine exhaust, will be collected during the microturbine testing stage of the LFG Feasibility Assessment. Inlet and outlet data will be compared to provide data on thermal destruction efficiency of both units.

MICROTURBINE ASSESSMENT

On behalf of The City of Calgary and its project partners, CH2M negotiated with CanMET Energy Technology Centre (CETC) for the use of a trailer-mounted Capstone 330 microturbine package, including gas compression and filtration equipment, instrumentation and control systems.

The microturbine package will be connected into the existing gas extraction system at the Shepard landfill site. The capacity of the microturbine is 30 kW, and the electrical power generated will be used for the fuel delivery system parasitic loads (blower, compressor, controls, trailer lighting, etc.); the remaining power will be used to offset a small portion of landfill site load. The assessment will commence at the end of April, 2002 and continue through to the end of June, 2002.

The Capstone 330 microturbine package had not yet been commissioned at the Shepard landfill at the time of publication; therefore, no assessment data is available. This topic will be discussed further during the paper presentation, and results will be made available upon request.

RENEWABLE ENERGY ASSESSMENT

As previously mentioned, Phoenix Engineering Ltd. was retained by W&RS, on behalf of its project partners, to assess the feasibility of producing wind and solar power from each of its three active landfills.

Preliminary site assessments discounted the viability of producing wind power from the East Calgary and Shepard landfills due to the proximity of buildings on the windward side of the sites, adjacent topography, and observed wind speeds. In addition, the solar assessment was limited to determining whether solar power would be a viable alternative for power site facilities purchasing power from the grid. This limitation was made due to the high cost of photovoltaic technology to produce saleable electricity.

A 50-metre tall wind tower was erected in November of 2001 on the windward (northwest) corner of the Spyhill landfill site. Monitoring equipment is stationed at the 10, 30- and 50- metre elevations, and data is logged and analyzed monthly. To ensure that an accurate snapshot of the site's wind and environmental conditions is obtained, it is expected that the assessment will continue until November 2002.

Although the wind-power assessment is in its infancy, preliminary results show that the Spyhill site holds much promise for producing wind power. Statistics for the months of November to March 2002 show very good energy yields at the 50 metre and extrapolated 78 metre wind heights (MWh), with values averaging approximately 160 MWh (with a Vestas V47-660) and 510 MWh (with a V80-1800) respectively. In addition, the capacity factor is being determined at each of these heights, which is defined as the ratio of average power that can be produced at the site by the wind turbine's maximum power output. The capacity factors to date average 34.3 percent at 50 metres and 39.4 at 78 metres. In comparison, it is generally accepted that sites with capacity factors in the mid-30s are considered extremely viable wind turbine locations. In fact, many European countries will place a wind turbine on sites with capacity factors in the high 20s. Further to this, it is interesting to note that the Spyhill site has a lower average and more constant wind speed than many other potential wind tower locations, such as those in the Southern Alberta area. This means that a wind turbine will produce power more often, as it will not be subject to the excessive wind speeds which cause the turbine to shut down.

FUTURE AND POTENTIAL PROJECTS

The City of Calgary intends to proceed with the design and installation of LFG collection and destruction infrastructure at the three active landfill sites. The design of the proposed collection system will commence in the fall of 2002, with implementation expected in spring of 2003. Pending the successful implementation of the LFG collection system and analysis of the LFG assessment, W&RS and its project partners will explore opportunities to better utilize the LFG and, more specifically, its methane component. This utilization project will be subject to the terms and conditions of an extended partnership agreement between W&RS, ENMAX and EnCana, in addition to the requirements of a full environmental review and approval of the appropriate provincial and federal regulators.

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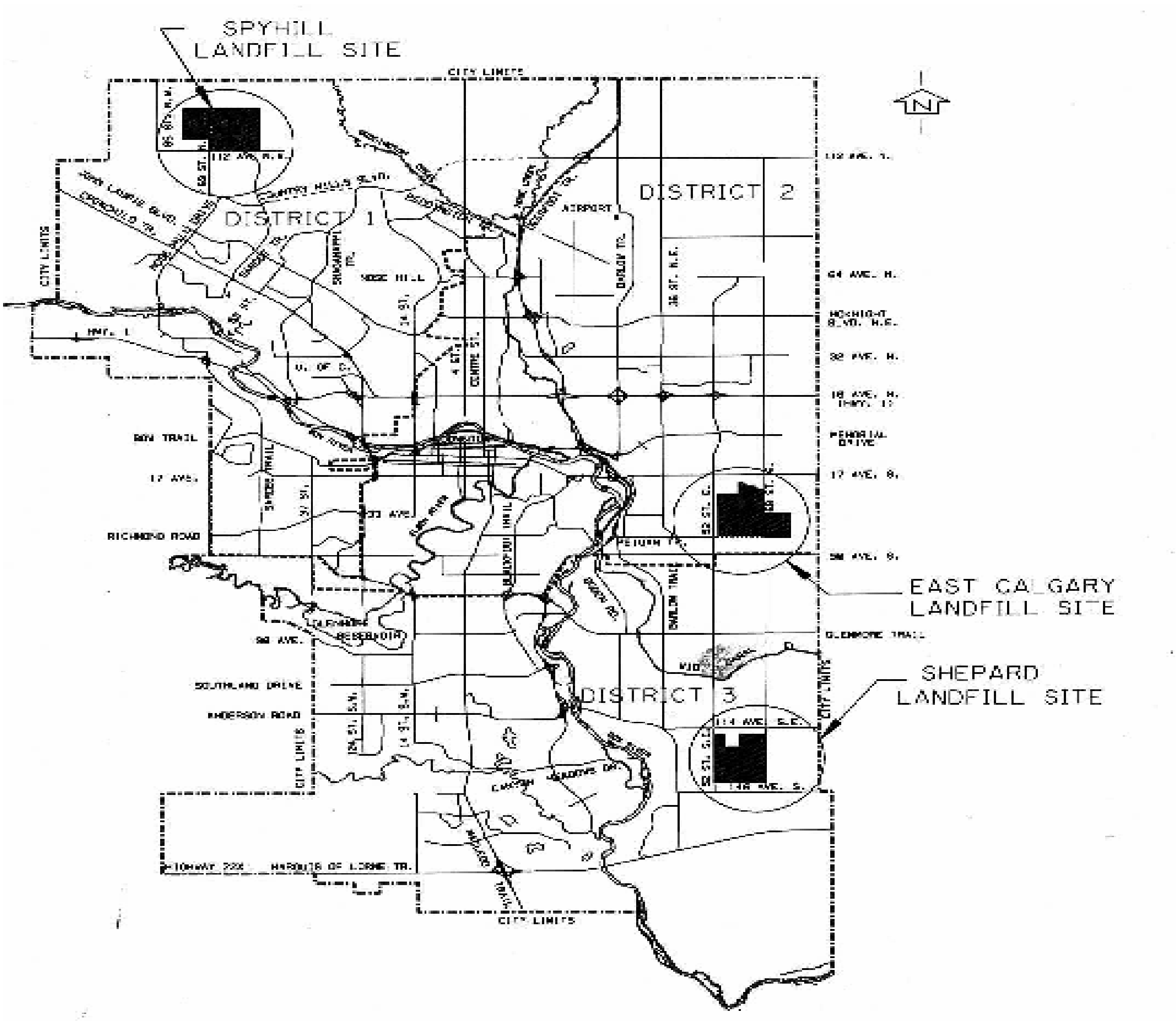


FIGURE 1 - CITY OF CALGARY LANDFILL SITE LOCATIONS

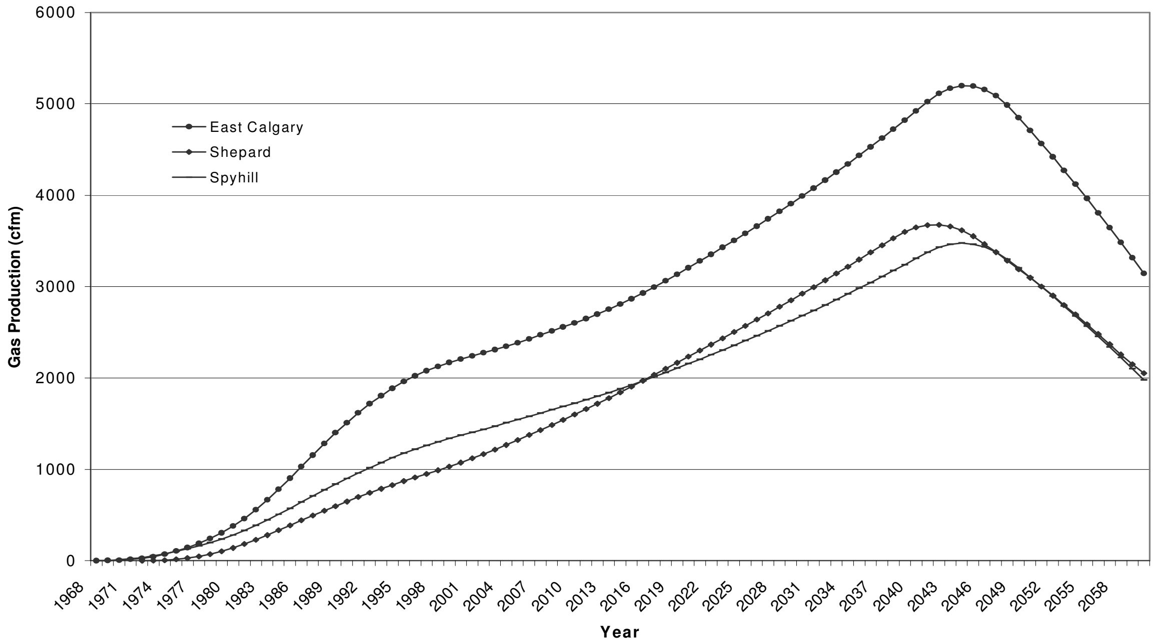
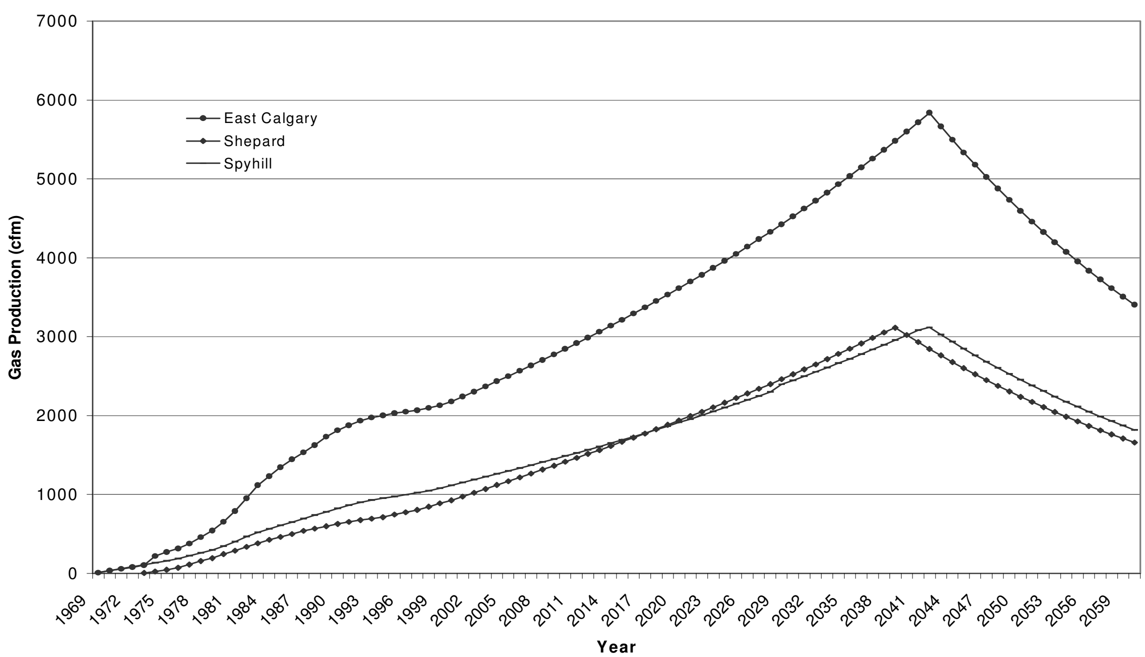


FIGURE 2. CITY OF CALGARY LFG PROJECTIONS CH2M LANDFILL GAS GENERATION MODEL



East Calgary: Lo = 120 m^3/Mg, k = 0.030 1/yr
Shepard: Lo = 80m^3/Mg, k = 0 030 1/yr
Spyhill: Lo = 105m^3/Mg, k = 0.030 1/yr

FIGURE 3: CITY OF CALGARY LFG PROJECTIONS EPA LANDGEM MODEL VER. 2.01

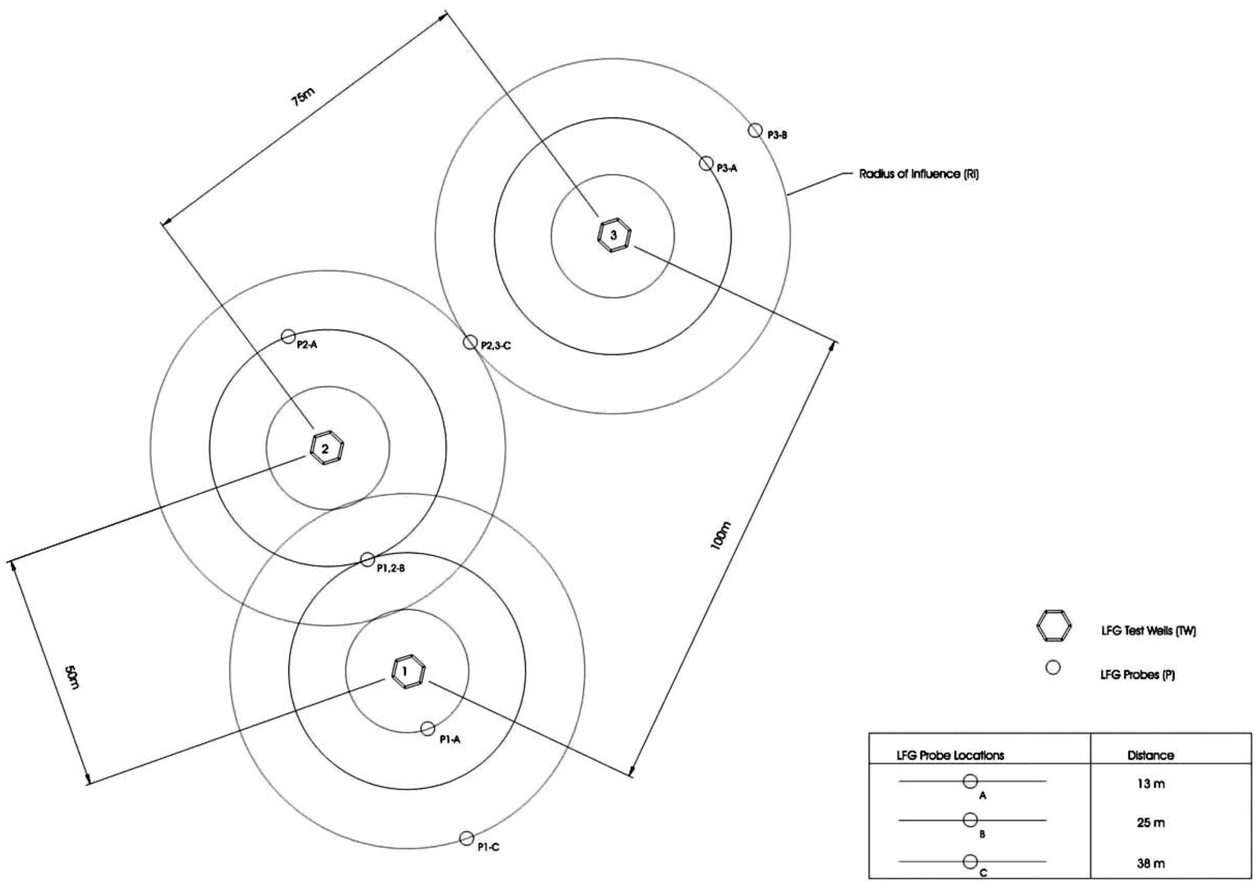


FIGURE 4. LANDFILL GAS TEST WELL AND PRESSURE PROBE CLUSTER PATTERN

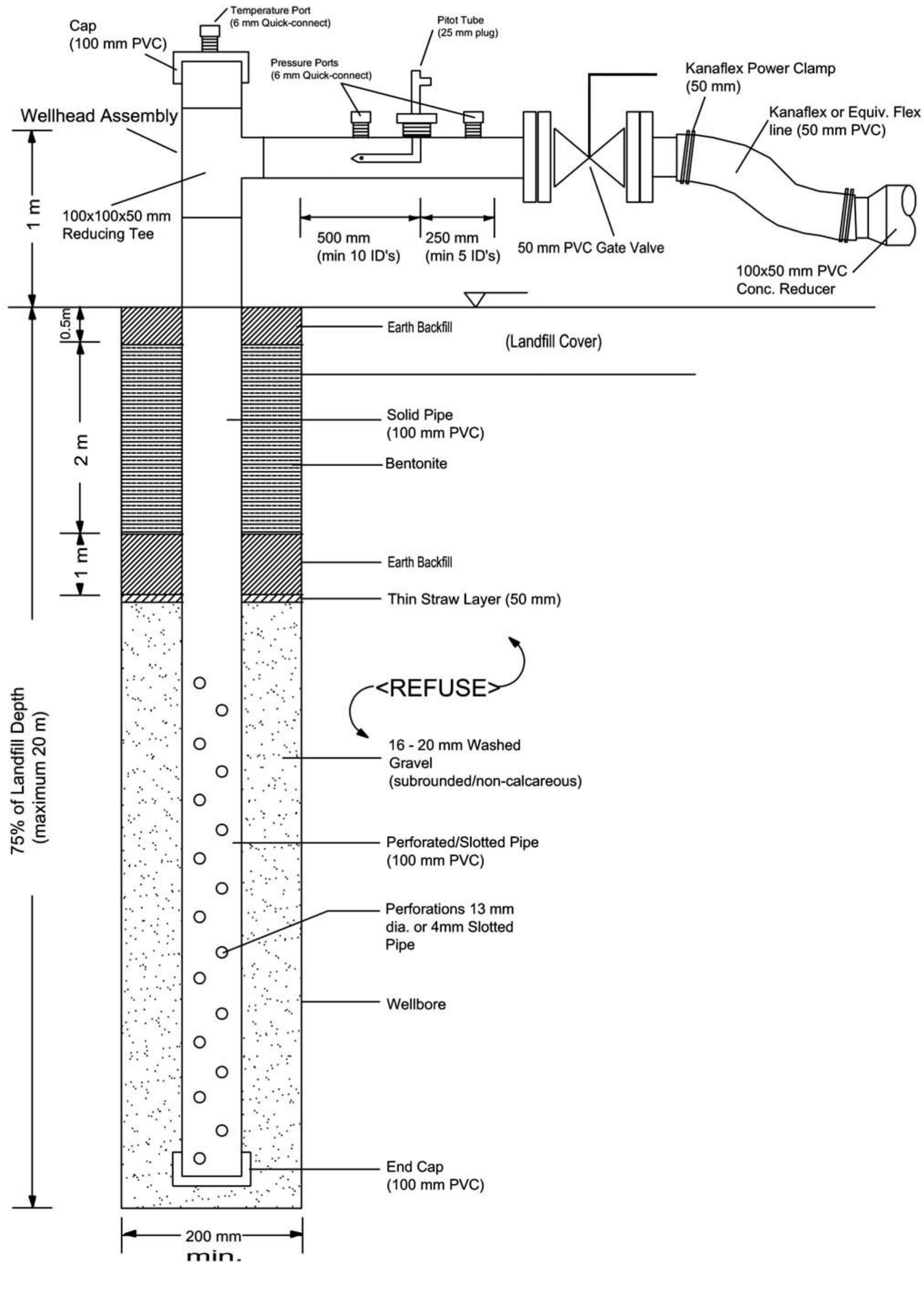


FIGURE 5. LANDFILL GAS TEST WELL DETAIL

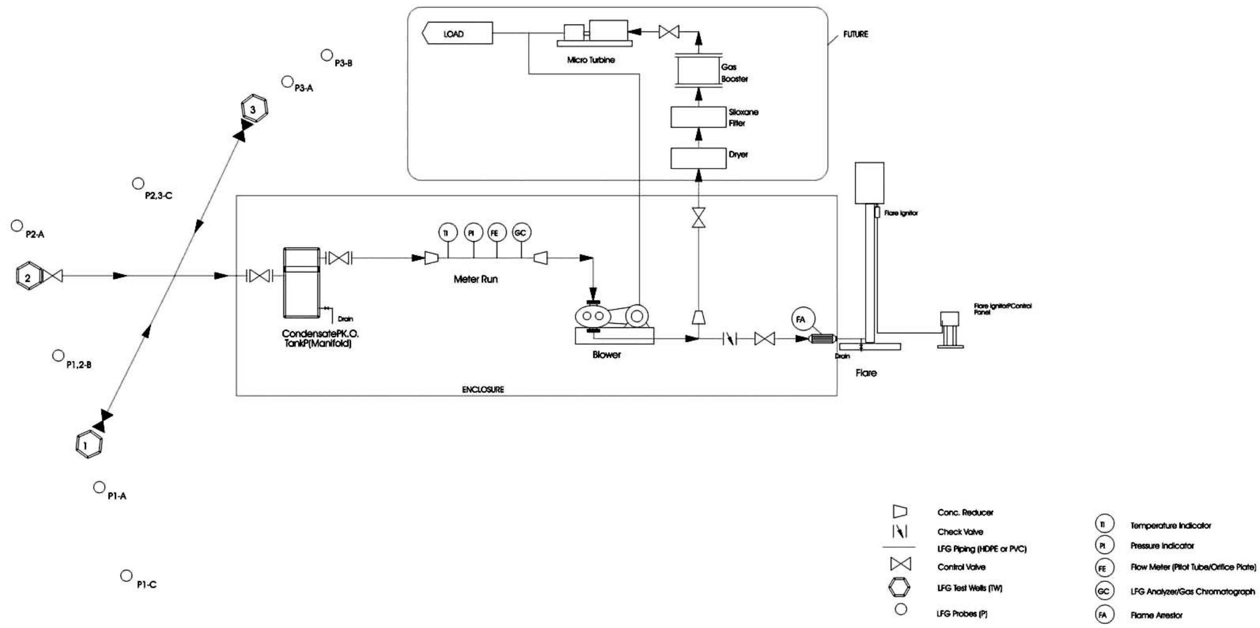


FIGURE 6. LANDFILL GAS TEST EQUIPMENT CONFIGURATION