Comparative Studies of Three Different Horizontal Landfill Gas Collector Design

Posted By Toraj Ghofrani On July 12, 2016 @ 7:24 am In Landfill Management | 2 Comments

To collect all landfill gas (LFG) that microbes generate in a municipal landfill, it would be ideal if LFG collection (flow) rate could be directly proportional to vacuum zone of influence. Unfortunately, the laws of fluid mechanics places flow rates inversely proportional to vacuum zone of influence, and there lies the biggest challenge to LFG engineers. While LFG flow rate and vacuum zone of influence are adjustable through aboveground control valves located on each collector head, the effectiveness and efficiency of an LFG collection system and vacuum zone of influence are locked in subsurface collectors' perforation size.

Furthermore, landfill airspace capacity is best spent for the disposal of municipal refuse, but the reality of most municipal landfills is that the horizontal and vertical LFG collectors can easily exceed several miles of piping and backfill materials, reducing valuable landfill airspace utilization. To maximize the landfill air space capacity, most landfill engineers design LFG collectors with maximum capturing zone of influence while matching the rate of LFG collection to that of the LFG generation. Any excessive increase in vacuum zone of influence in the upper lifts of the landfill may lead to air intrusion, a primary safety hazard for landfill operators, and any excessive decrease in zone of influence may lead to an increase in the number of LFG collectors for adequate redundancy, which in turn reduces landfill air space utilization for refuse disposal.

To better examine the efficiency and effectiveness of pipe perforation in an LFG collection system, three different LFG collector perforation designs were tested and monitored in the same 800-foot trench at Cedar Hills Regional Landfill, located in Maple Valley, WA. One LFG collector comprised of a 6-inch-diameter high-density polyethylene (HDPE) pipe with six 1/2-inch perforations, 60 degrees apart and 6-inch on center. The second LFG collector comprised of 6-inch-diameter HDPE pipe with one 1/8-inch perforation, rotating 90 degrees and 5 foot on center. The third LFG collector was a "Minitube-Blanket" comprised of 1-inch-diameter corrugated polypropylene pipe with two 1-millimeter-diameter perforations per valley, 180 degrees apart rotated 90 degrees and needle punched between two non-woven geotextile fabrics, a product of AfitexTexel.

This paper presents comparative studies of the vacuum zone of influence, LFG flow rate, methane, oxygen (O_2), nitrogen (N_2), carbon dioxide (CO_2), and temperature-monitoring data collected between September 2015 and March 2016 from the above-referenced LFG collectors.

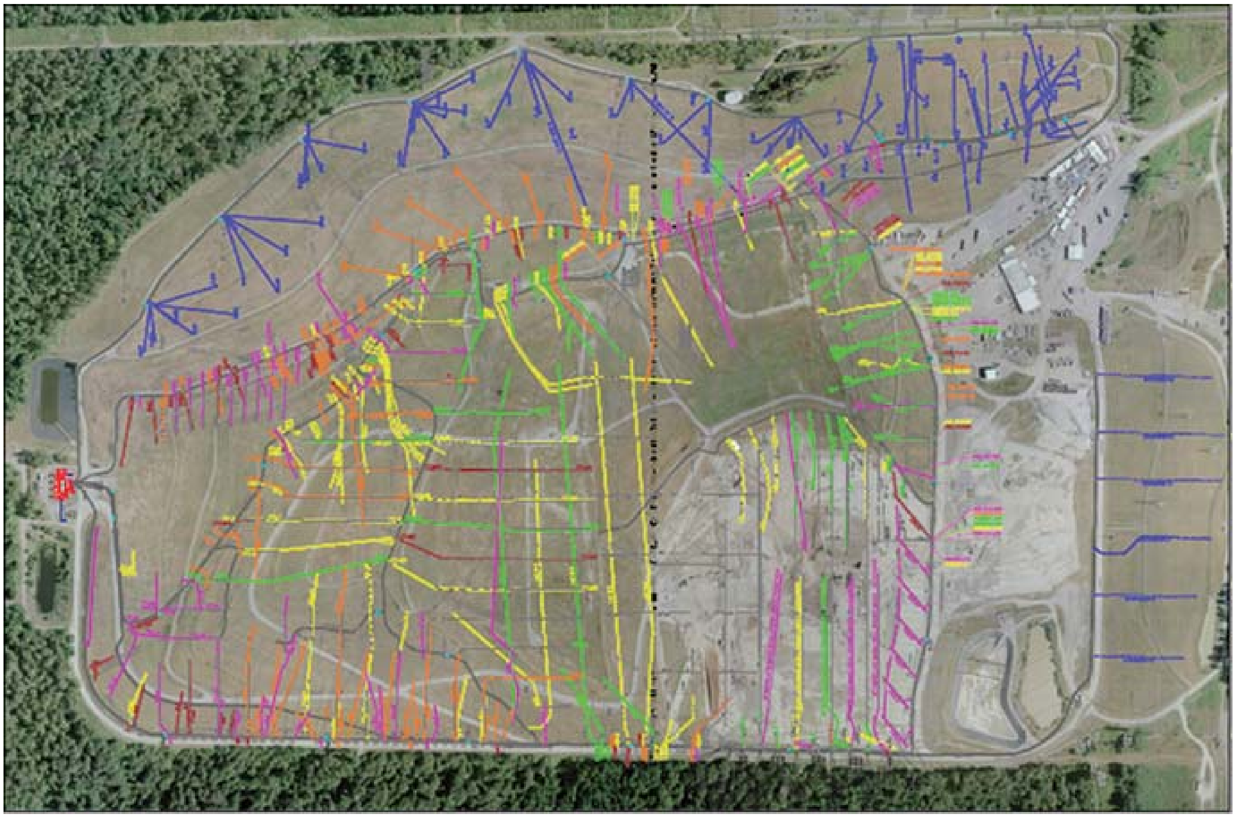


Figure 1. Horizontal and vertical LFG collectors at Cedar Hills Regional Landfill in Washington

Landfill Background

King County Solid Waste Division (KCSWD) owns and operates the Cedar Hills Regional Landfill (CHRLF) located in Maple Valley (Figure 3). CHRLF is one of the largest municipal solid waste landfills in the Pacific Northwest with 920 acres in area, approximately 406 acres of which is available for municipal solid waste (refuse) disposal and support functions, and the rest is buffer zone. CHRLF serves a population of 1.3 million in 37 of the 39 cities located in King County, and has been in operation since 1965, with 18.3 million cubic yards (CY) permitted capacity. There are currently nine disposal areas at the site (Figure 4). Three pre-1986 disposal areas are unlined, while the post-1989 areas are all lined. Six of the disposal areas are closed with final covers and two of the disposal areas are partially closed with interim cover, leaving one active area for daily refuse disposal handling. The average thickness of refuse areas ranges from 140 to 240 feet, leaving more than 200 feet of buffer zone between the floors of refuse areas and the regional groundwater beneath the site. Each day, approximately 2,500 tons of refuse is delivered to CHRLF for disposal with an in-situ density of nearly 1,600 pounds per cubic yards (Lbs/CY). At current incoming refuse and recycling trends, CHRLF is expected to reach its final capacity in 2040.

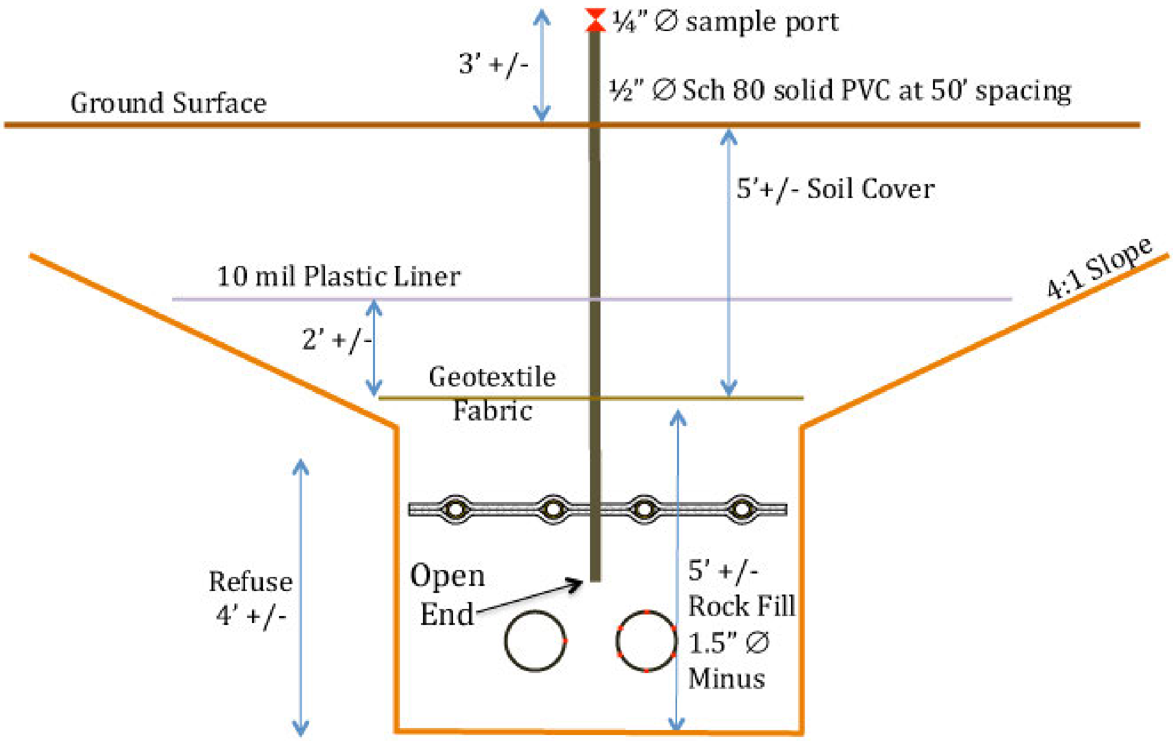


Figure 2. Test trench construction profile

Since 2009, approximately 10,000 standard cubic feet per minute (SCFM) of high-quality LFG is collected from nine refuse disposal areas and conveyed to the Bio Energy Washington (BEW) plant, a KCSWD tenant at CHRLF. On average, BEW converts LFG to approximately 4,500 million BTUs (MMBTUs) per day pipeline-quality natural gas. This has significantly decreased CHRLF's greenhouse gas emissions, as part of KCSWD's strategic commitment to attenuate the global warming effect. During routine operation and maintenance plans or inadvertent power outages, LFG is conveyed to CHRLF's North Flare Station for combustion. Additionally, approximately 800 SCFM of low-quality LFG is also conveyed to the North Flare Station for a continuous combustion.

LFG Collection Design Trends

As far as LFG conveyance design is concerned, the ideal LFG collection rate is the one that matches the rate at which LFG is generated by microbes. There are no exact sciences to estimate the rate at which microbes generate LFG due to many physical, chemical, and biological factors, including microbial diversity, refuse organic content, moisture, pH, temperature, and age. Predictive models have been developed by the United States Environmental Protection Agency (USEPA) to conservatively estimate LFG generation in municipal landfills based on first-order refuse decomposition rate (LandGEM Version 3.02 Model).

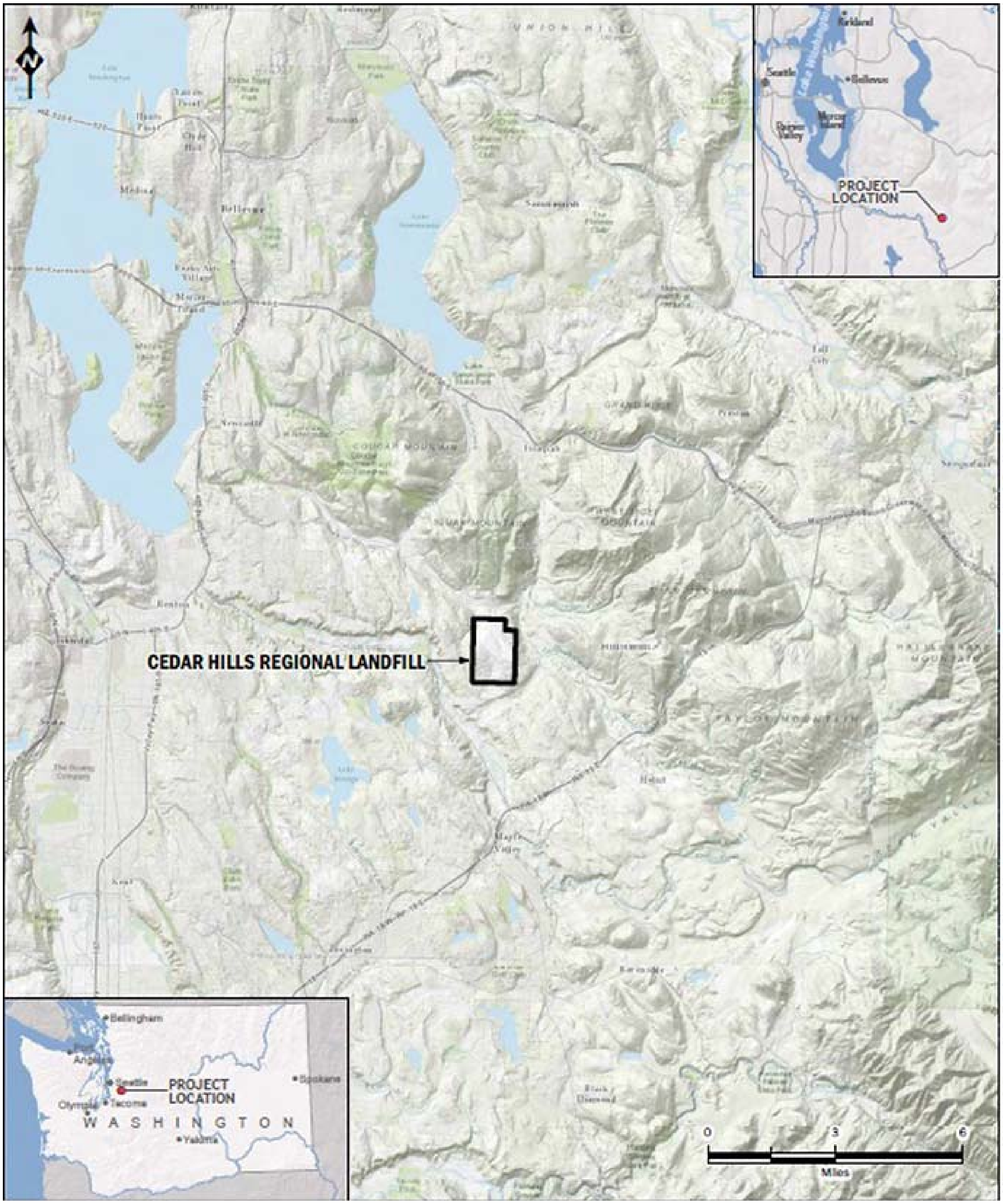


Figure 3. Location of Cedar Hills Regional Landfill in Washington

Other Pneumatic, Biokinetic, and Baro Pneumatic models have also been developed that require site-specific test data to define parameters for model input (EMCON 1988, El Fadel et al. 1996, Tolaymat et al. 2010, and Bentley et al. 2003). However, what these models have in common is significant variation in estimating LFG generation rate from site to site. These variations are often inextricably entwined with site conditions and assumptions made for using default values (Scharff and Jacobs 2006 and Bentley et al. 2003). All predictive model results for LFG generation, therefore, should be checked against the reality of monitored and measured LFG collection in the field. At CHRLF, more than 90% of the LFG collected are converted to renewable energy in form of pipeline-quality natural gas and electricity, and the rest are flared. Using the reality of the renewable energy as a "yard stick" against the USEPA predictive model estimates of LFG generation, the volume of LFG collected at CHRLF matches closely with the model predicted LFG generation. This is further supported through extensive surface monitoring and perimeter monitoring of LFG.

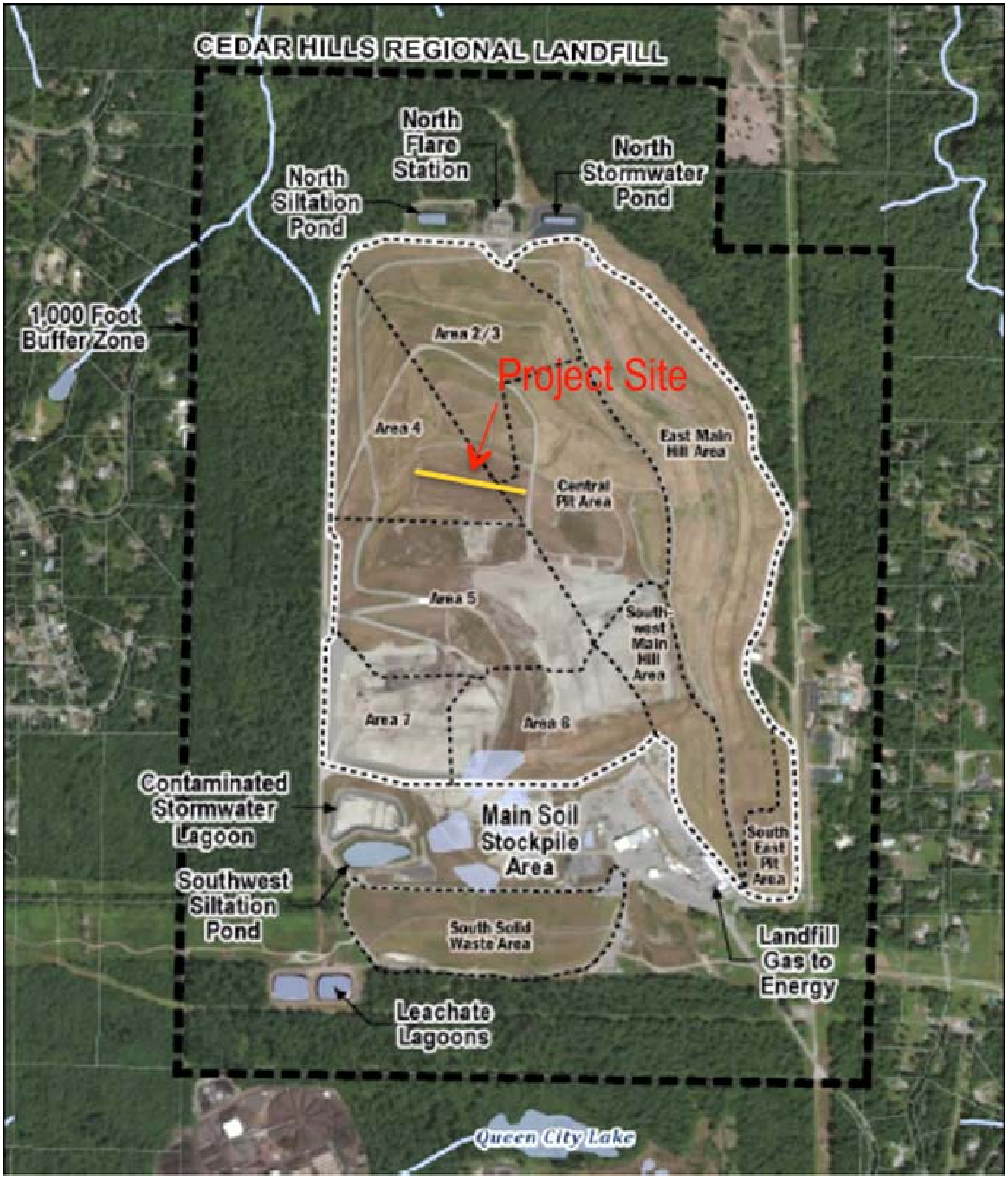


Figure 4. Project site and refuse disposal areas at Cedar Hills Regional Landfill

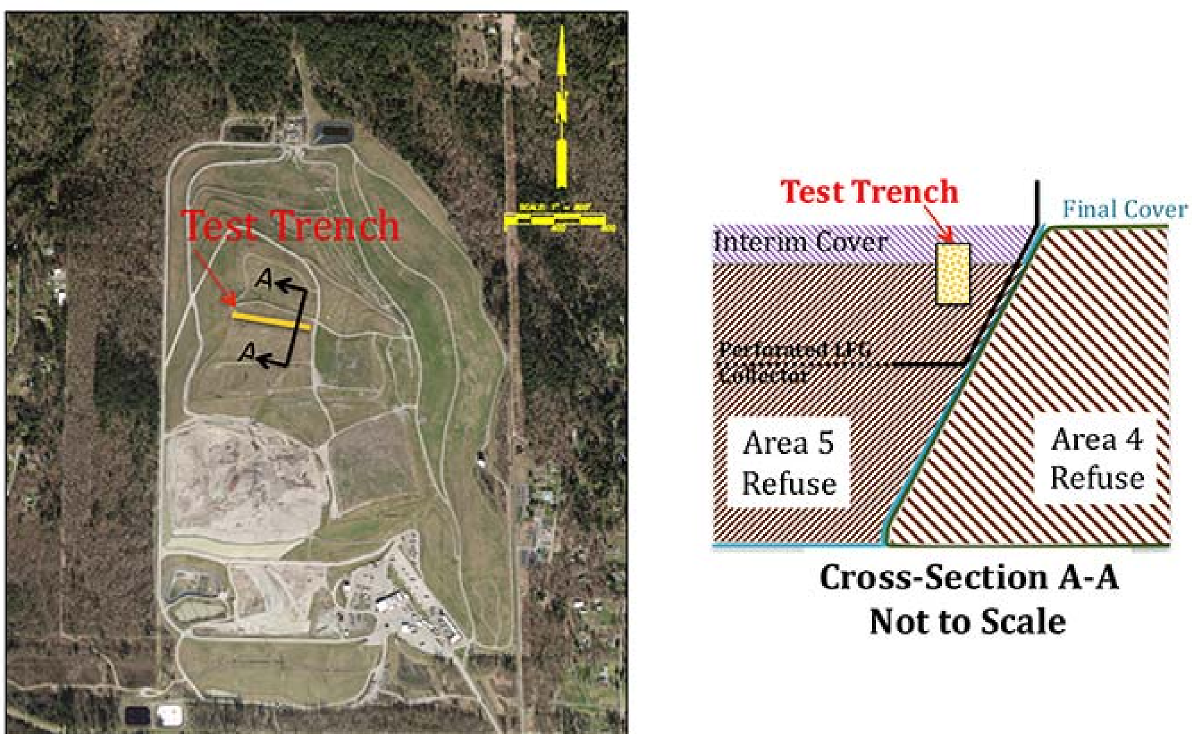
To maximize the landfill air space capacity, most landfill engineers design LFG collectors with adequate capacity and overlapping vacuum zone of influence (ZOI) to ensure capturing of all the LFG generated by microbes. Any excessive increase and overlapping of ZOI may lead to air intrusion, a primary safety hazard for landfill operators near the upper region of refuse areas. On the other hand, insufficient vacuum ZOI may lead design engineers to increase the number of LFG collectors to ensure adequate redundancy, reducing refuse air space.

At CHRLF, LFG is collected through a network of aboveground headers and more than 630 horizontal and vertical LFG collectors (Figure 1). These LFG collectors are comprised of nearly 50+ miles of approximately 2-foot-by-4-foot rock-filled trench and piping systems that occupy more than 70,000 CY of landfill airspace. At current tipping fees of nearly $130 per ton, the 70,000 CY loss of airspace could amount to $7.3 million.

At a steady state, the LFG collection effectiveness and efficiency depend on two primary parameters: LFG collection rate and vacuum ZOI, both of which are controlled by a dedicated valve atop each LFG collector. As these valves open or close, their effect on LFG flow rate and vacuum ZOI are, unfortunately, inversely proportional. To minimize vacuum loss and to provide a uniform distribution of vacuum ZOI along the perforated section of the LFG collectors, the perforation size and perforation frequency along the pipe play critical role in LFG collection design.

To better examine the efficiency and effectiveness of pipe perforation in an LFG collection system, three different LFG collector designs were tested and monitored in the same 800-foot trench at CHRLF:

1. Conventional Design: Comprised of a 6-inch-diameter HDPE pipe with six 1/2-inch perforations, 60 degrees apart and 6-inch on center. The sum of all perforated areas along the 700 feet of this horizontal collector amounted to approximately 11.5 square feet (ft.^{2}).
2. Alternative Design: Comprised of 6-inch diameter HDPE pipe with one 1/8-inch perforation, rotating 90 degrees and 5 foot on center. The sum of all perforated areas along the 700 feet of this horizontal collector amounted to approximately 0.01 ft.^{2}
3. Minitube-Blanket Design: Comprised of 1-inch-diameter corrugated polypropylene pipe with two 1-millimeter-diameter perforations per valley, 180 degrees apart rotated 90 degrees per valley, and needle punched between two non-woven geotextile fabrics. The sum of all perforated areas along the 700 feet of this horizontal collector amounted to approximately 4.5 ft.^{2}



[3]

Figure 5. Location of test trench where Refuse Area 5 with interim cover leans against Refuse Area 4 with final cover

The location of the 800-foot test trench was selected near the ground surface where one refuse disposal area with interim cover was leaning against another refuse disposal area with final cover (Figure 5).

Test Trench Construction

As presented in Figure 2 and photos 1 through 10, the test trench included the Conventional, Alternative, and Minitube-Blanket LFG collectors, along with geotextile fabric, 10-mil plastic liner, 5 feet of 1.5-inch minus rock fill material, and approximately 5 feet of soil cover. A 1/2-inch-diameter PVC Schedule 80 was placed open-ended in the rock fill material at the center of the three LFG collectors, and extended more than 3 feet above the surface ground with a sampling port for vacuum ZOI measurements. These vacuum ports were installed 50 feet apart along the length of the collectors. These ports were not connected to any of the individual collectors. Instead, they were located in the rock fill materials at the center of the LFG collection trench.

[4]

Photo 1. Test trench in refuse area

[5]

Photo 2. 1.5-inch minus rock fill material for pipe bed

[6]

Photo 3. Minitube-blanket LFG collector

[7]

Photo 4. Conventional LFG collector

[8]

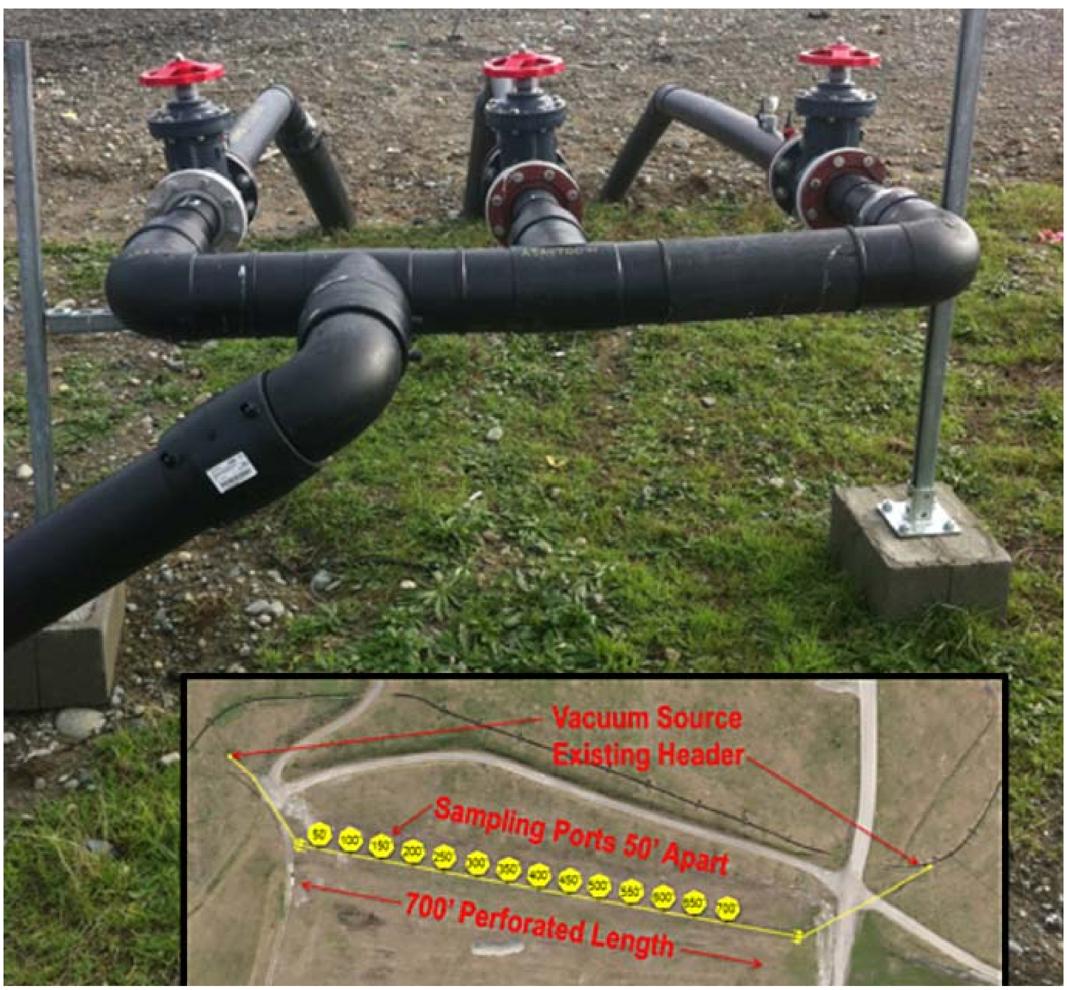
Photo 5. Alternative LFG collector

[9]

Photo 6. All three LFG collectors inside test trench

[10]

Photo 7. Minitube-blanket end connection to vacuum source

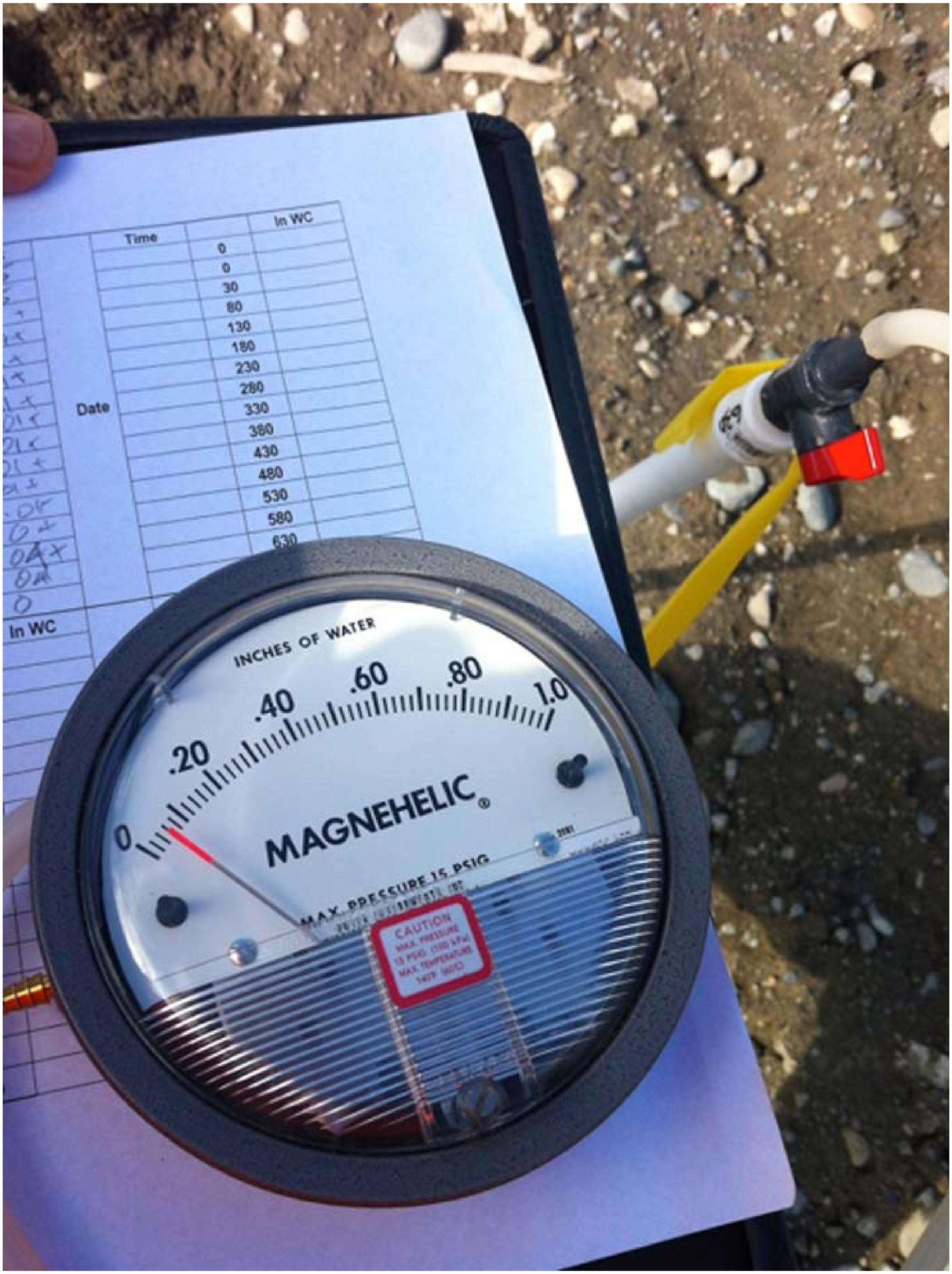


[11]

Photo 8. Three LFG collectors above ground finish

[12]

Photo 9. Vacuum measuring ports in background



[13]

Photo 10. Field vacuum measurements

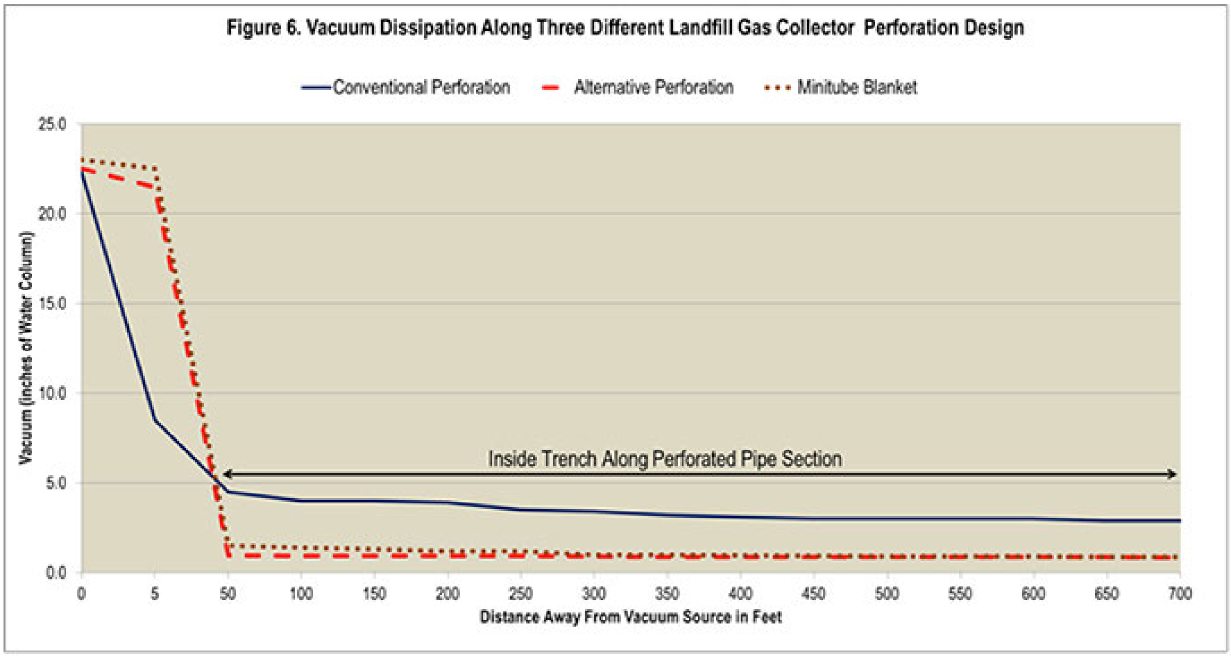
Photo 11. Field fixed gases measurement using GEM-5000

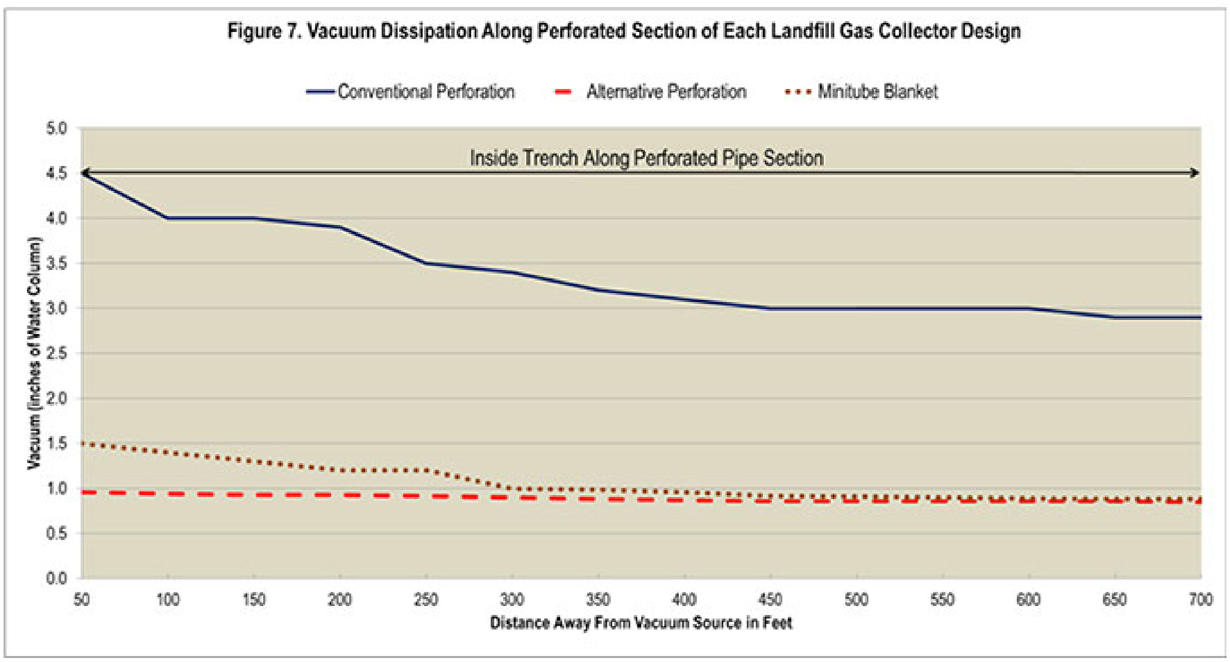
The three LFG collectors were extended above the ground surface, each with its own control valve and sampling ports for measuring LFG flow rate, methane (CH_4), O_2, N_2, CO_2, and temperature. Due to variation in depth of refuse, the west end of the 800-foot test trench was located several feet lower in elevation as compared to the East side of the test trench. In anticipation of condensate block on the west side of the trench, vacuum source of about 23 inches of Water Column (WC) were provided to the three LFG collector heads from west and east ends of the same header (Photo 8). However, only one vacuum source was used at a time while the valve to the second vacuum source was kept closed during the test.

Study Limitations

There are several notable limitations to this study:

1. The vacuum ports were only placed in the trench along the LFG collectors' length in an East-West direction on the top deck Area 5 (Figure 5). No vacuum ports were installed perpendicular to the trench in north-south direction since the trench was right at the edge of Area 4 with a final cover that could not be punctured. To the south, there were active LFG collectors under vacuum that would have interfered with vacuum readings. As a result, vacuum Radius of Influence could not be estimated using vacuum ports located transversely to the vacuum source. Instead, vacuum ZOI was evaluated based on vacuum readings at the source and vacuum reading at the ports located linearly along the length of the trench.
2. There were synergetic effects from the three collector located in the same trench, however, these synergetic effect were considered minor with respect to vacuum measurements. It took approximately six seconds from the time that a valve at the LFG collector head was opened for the vacuum to reach the last vacuum probe located 700 feet away from the vacuum source. It also took less took less than five minutes for the vacuum to completely dissipate at the last vacuum probe located 700 feet away, once the valve was closed to cut off from the vacuum source. Therefore, all vacuum and fixed gas readings were collected by allowing adequate time for the test trench to reach equilibrium.
3. Considering the daily barometric fluctuations at the site, it was extremely difficult to keep all three LFG collectors under the same vacuum and flow rates, while balancing the LFG collection based on maximizing CH_4 concentrations and minimizing O_2 and N_2 below permitted limits. Consequently, long-term operation under steady state was not sustainable through continuous operations, regardless of which LFG collectors were used. Therefore, comparative studies of the three LFG collectors were made in general and non-absolute terms by not only presenting the range of the data, but also documenting the potential peak performances.
4. With the exception of the first few weeks, the majority of the data were collected at CHRLF during wet season. Since the test trench is located in an area with interim cover, precipitation and barometric fluctuations were not identical for all three LFG collectors. However, by running the test on each of the LFG collators over a lengthy continuous period of time, adequate opportunities were given to each LFG collector to respond to variation in precipitation and barometric fluctuations associated with the wet season and normalize the data.





[14]

Figure 6. Vacuum dissipation along three different LFG Collector Perforation Design
Figure 7. Vacuum dissipation along perforated section of each LFG Collector Design

Comparative Results of Vacuum Zone of Influence

Vacuum measurements were made at designated vacuum ports, using 0- to 1-inch WC range and 0- to 25-inch WC range Magnehelic gauges. Vacuum measurements were made from each of the Conventional, Alternative, and Minitube-Blanket LFG collectors during the same day and under the same ambient conditions, but not the same flow rate. Vacuum was applied to the three LFG collectors on the west side of the trench in mid-September 2015. The vacuum dissipation along each of the Conventional, Alternative, and Minitube-Blanket LFG collectors were recorded.

As presented in Figure 6 and Table 1 (**Click here for Table 1** [15]): The vacuum source of 22.3-, 22.5-, and 23.0-inch WC decreased to 8.5-, 21.5-, and 22.5-inch WC immediately after the control valves corresponding to LFG flow rates of 180, 59, and 59 SCFM at the Conventional, Alternative, and Minitube-Blanket LFG collectors, respectively. The higher the flow rate, the more the vacuum loss across the valve.

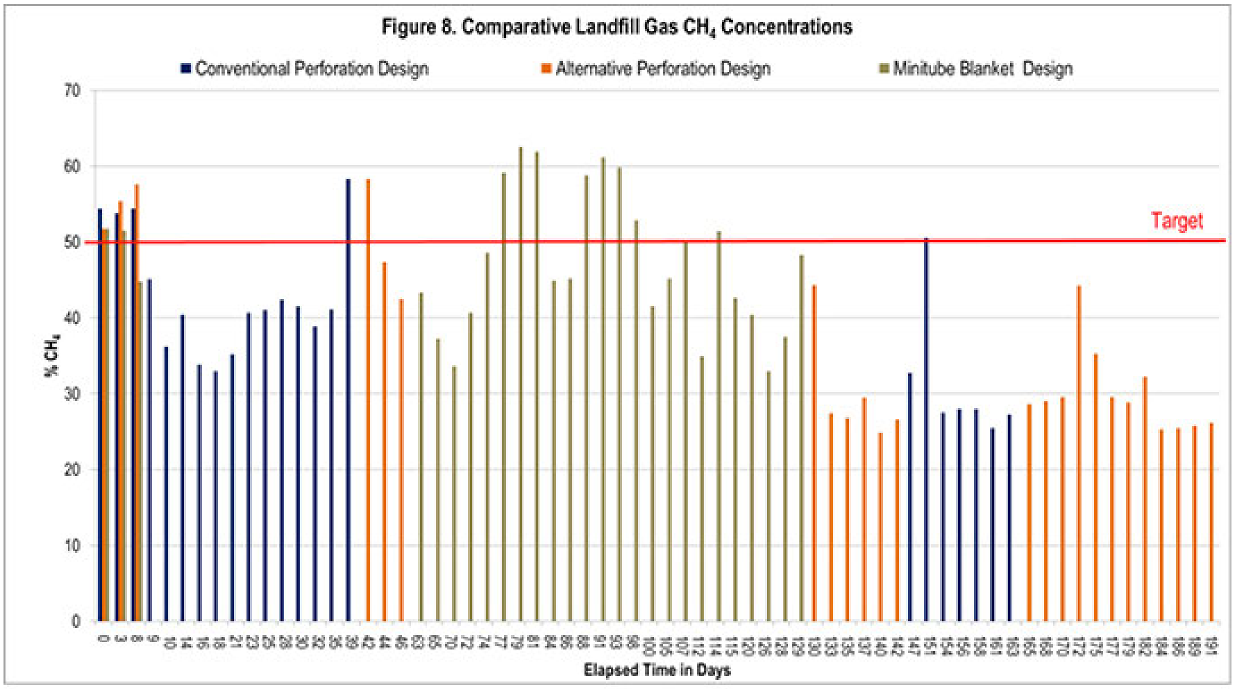
To compare the rate at which the vacuum is dissipated along the perforated section of the Conventional, Alternative, and Minitube-Blanket LFG collectors, vacuum readings were collected from each of the 50-foot apart ports (Photo 9) and results are presented, as follows:

- The vacuum inside the trench along the perforated section of the pipe dropped from 4.5-, 0.96-, and 1.5-inch WC to 2.9-, 0.85-, and 0.88-inch WC, or a vacuum loss of 36%, 11%, and 41% at the Conventional, Alternative, and Minitube-Blanket LFG collectors, respectively (Figure 7 and Table 1). These vacuum drops corresponded to the LFG flow rates of 180, 59, and 59 SCFM at the Conventional, Alternative, and Minitube-Blanket LFG collectors, respectively. As compared with the Conventional and Minitube-Blanket LFG collectors, the Alternative LFG Collector had the least vacuum drop across the trench length, indicating better distribution of ZOI across the 700 feet of the test trench.
- As LFG flow rate increased from 180 to 218 SCFM in the Conventional LFG Collector, its vacuum dropped from 2.9- to 2.8-inch WC. This reduction in ZOI was also present for Alternative and Minitube-Blanket LFG collectors. As LFG flow rate increased from 59 to 79 SCFM in the Alternative LFG Collector, its vacuum dropped from 0.85- to 0.80-inch WC; and similarly, as LFG flow rate increased from 59 to 83 SCFM in the Minitube-Blanket LFG Collector, its vacuum dropped from 0.88- to 0.85-inch WC, thus the higher the flow rate the lower the ZOI.

CH_4, O_2, N_2, CO_2, Temperature, Flow Rate, and Estimated CH_4 Mass Removal

The temperature was measured at the LFG collector heads using a field digital thermometer. The LFG flow rates and fixed gases (CH_4, O_2, N_2, and CO_2) were recorded at the Conventional, Alternative, and Minitube-Blanket LFG collector heads, using calibrated GEM-5000. To eliminate synergic effect of the three collectors operating simultaneously in the same test trench, each collector was tested individually for several weeks at a time while the remaining two collectors were kept offline by keeping their control valves closed. The several weeks of continuous, and yet intermittent operations during September 2015 through March 2016 allowed for adequate data collection corresponding with ambient barometric fluctuations while adjusting flow rates and vacuum ZOI to maintain optimum LFG quality with the following target parameters:

- CH_4 concentrations above 50%
- O_2 concentrations below 2%
- N_2 concentrations below 10%



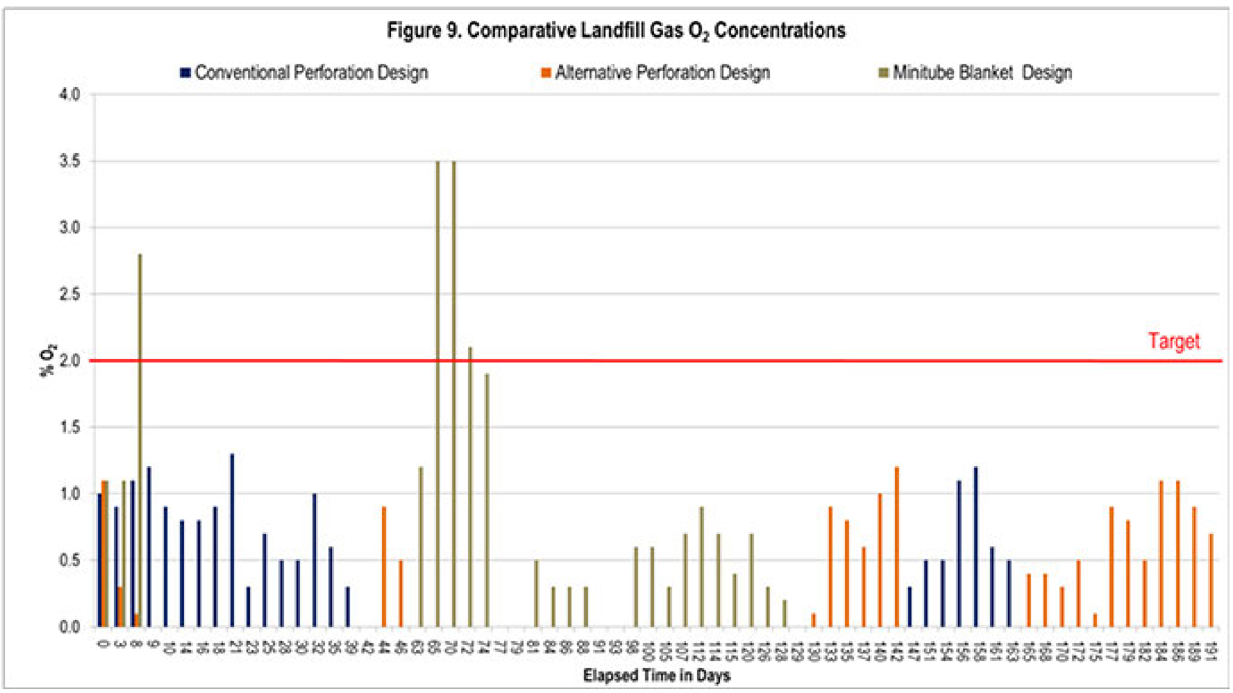
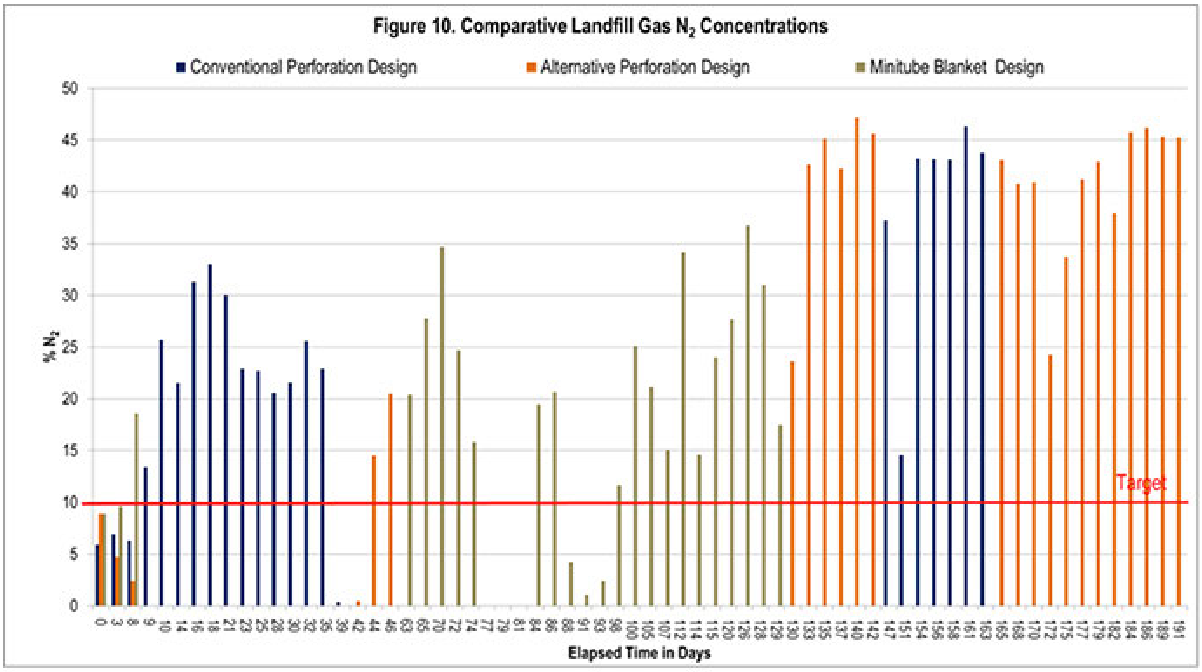


Figure 8. Comparative LFG CH_4 concentrations
Figure 9. Comparative LFG O_2 concentrations



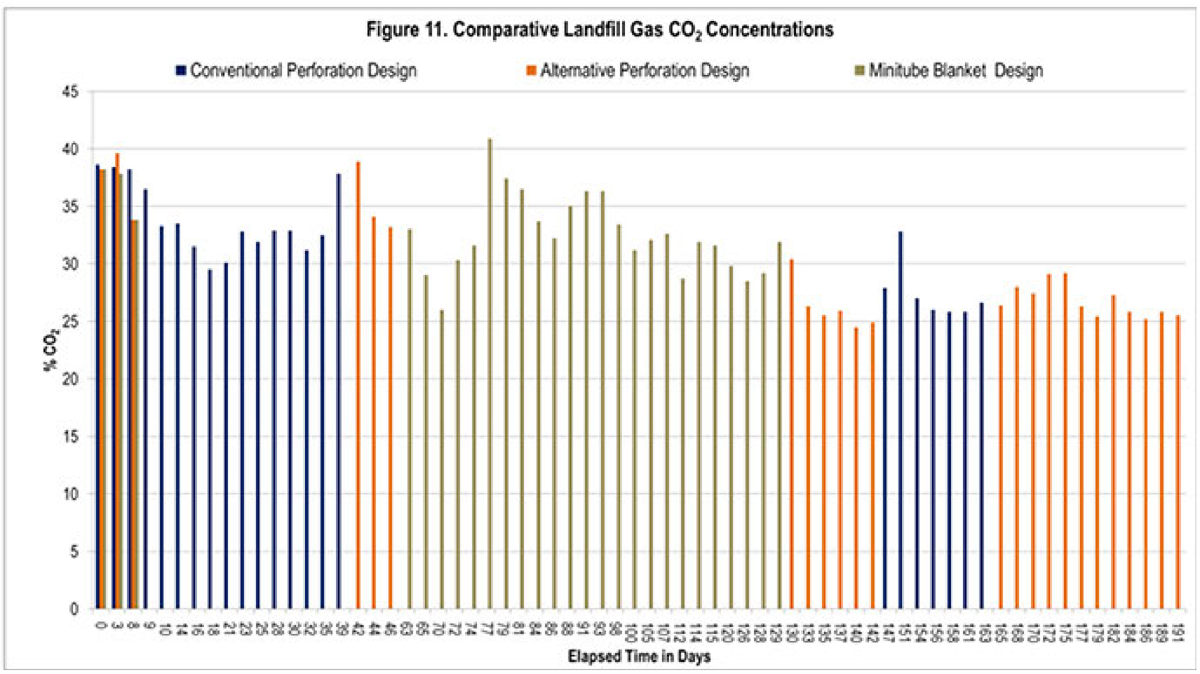
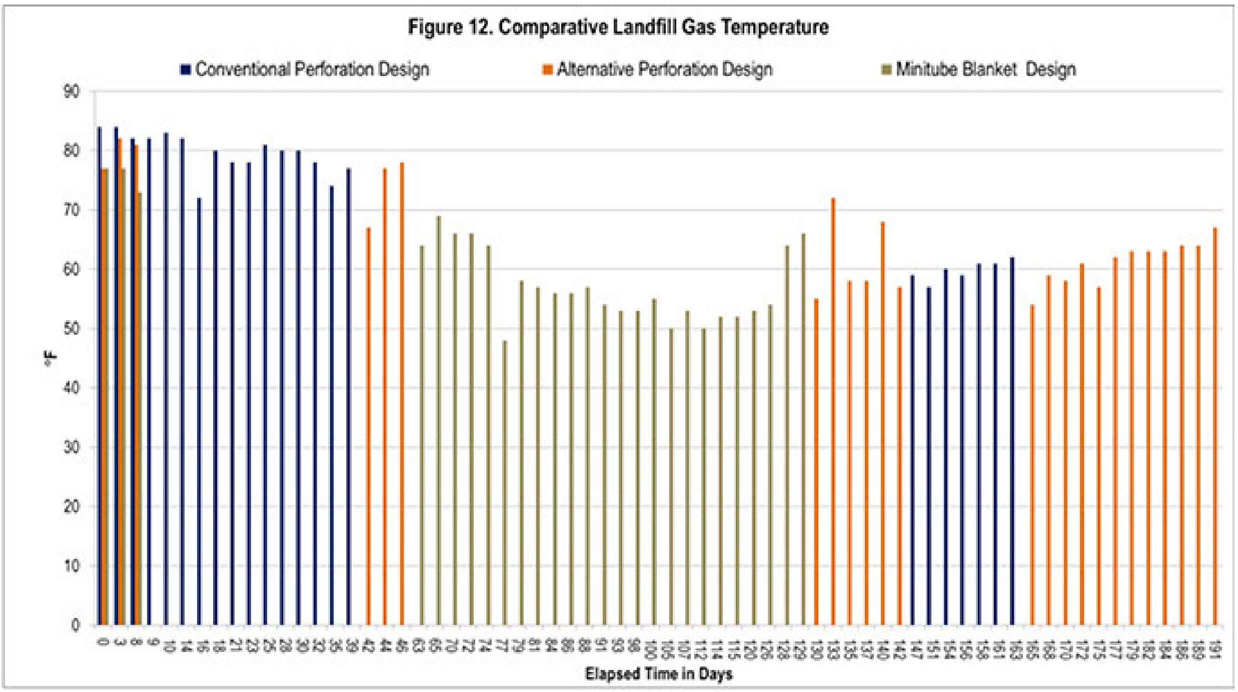


Figure 10. Comparative LFG N_2 concentrations
Figure 11. Comparative LFG CO_2 concentrations

As presented in Table 2 **(Click here for Table 2)**: [16]

- The CH_4 concentrations ranged from 25 to 58% for both Conventional and Alternative LFG collectors, and 33 to 63% for the Minitube-Blanket LFG collector (Figure 8).
- The O_2 concentrations ranged from 0.3 to 1.3%, 0.0 to 1.2%, and 0.0 to 3.5% for the Conventional, Alternative, and Minitube-Blanket LFG collectors, respectively (Figure 9). Similarly, the N_2 concentrations ranged from 0.0 to 46%, 0.0 to 47%, and 0.0 to 37% for Conventional, Alternative, and the Minitube-Blanket LFG collectors, respectively (Figure 10). This was despite attempts to adjust the O_2 and N_2 concentration below 2% and 10%, respectively. The elevated concentration of O_2, and especially N_2, are indicative of air intrusion due to the proximity of the trench near the ground surface.
- The CO_2 concentrations were similar for all three LFG ranging from 26 to 30%, 25 to 40%, and 26 to 41% for the Conventional, Alternative, and Minitube-Blanket LFG collectors, respectively (Figure 11).

- The temperature variation ranged from 57°F to 84°F, 55°F to 82°F, and 48°F to 77°F for the Conventional, Alternative, and Minitube-Blanket LFG collectors, respectively (Figure 12). These seasonal temperature readings were less than the permitted 130°F for LFG. As compared to similar temperature ranges for Conventional and Alternative LFG collectors, the Minitube-Blanket LFG collector had a lower range of temperature variation.
- The LFG flow rate ranged from 28 to 218 SCFM, 30 to 98 SCFM, and 29 to 235 SCFM for the Conventional, Alternative, and Minitube-Blanket LFG collectors, respectively (Figure 13). Combining the effects of LFG flow rates and CH_4 concentrations expressed in MMBTU per day, the heating content for the LFG collected from the three collators ranged from 15 to 173 MMBTU per day, 19 to 66 MMBTU per day, and 14 to 165 MMBTU per day for the Conventional, Alternative, and Minitube-Blanket LFG collectors, respectively (Figure 14). As compared to similar flow rate and LFG heating valve ranges for the Conventional and Minitube-Blanket LFG collectors, the Alternative LFG collector had a lower range of LFG collected heating content.



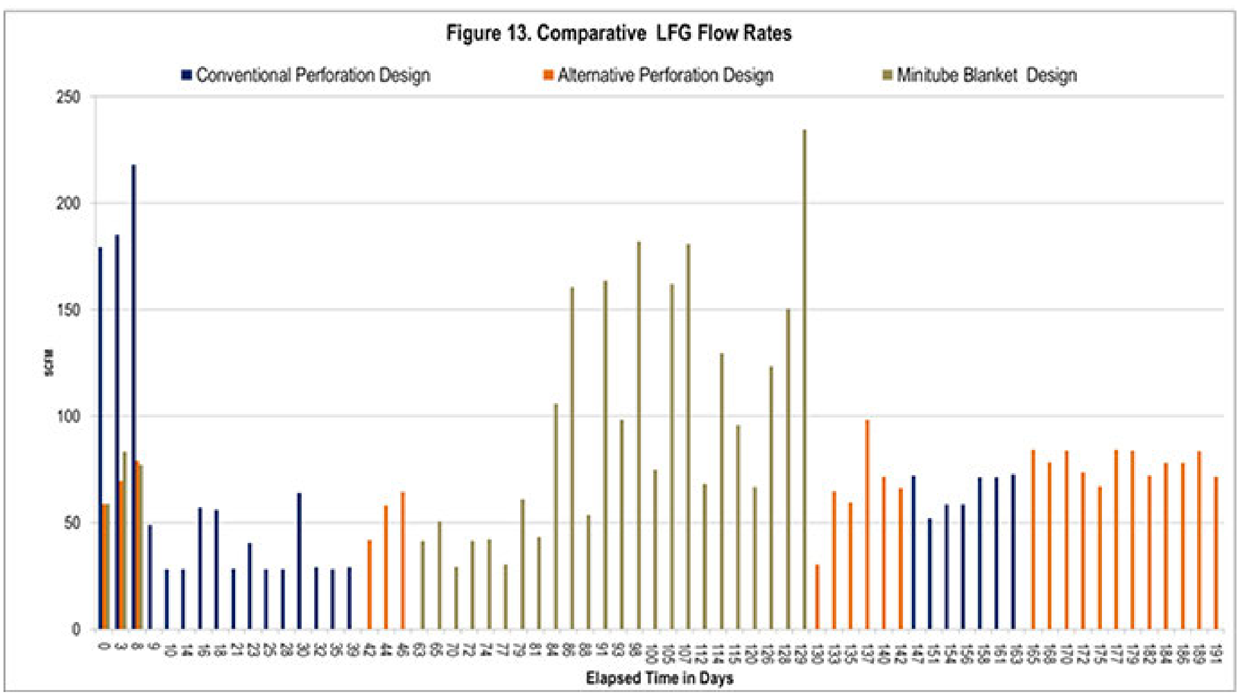


Figure 12. Comparative LFG temperature
Figure 13. Comparative LFG flow rates

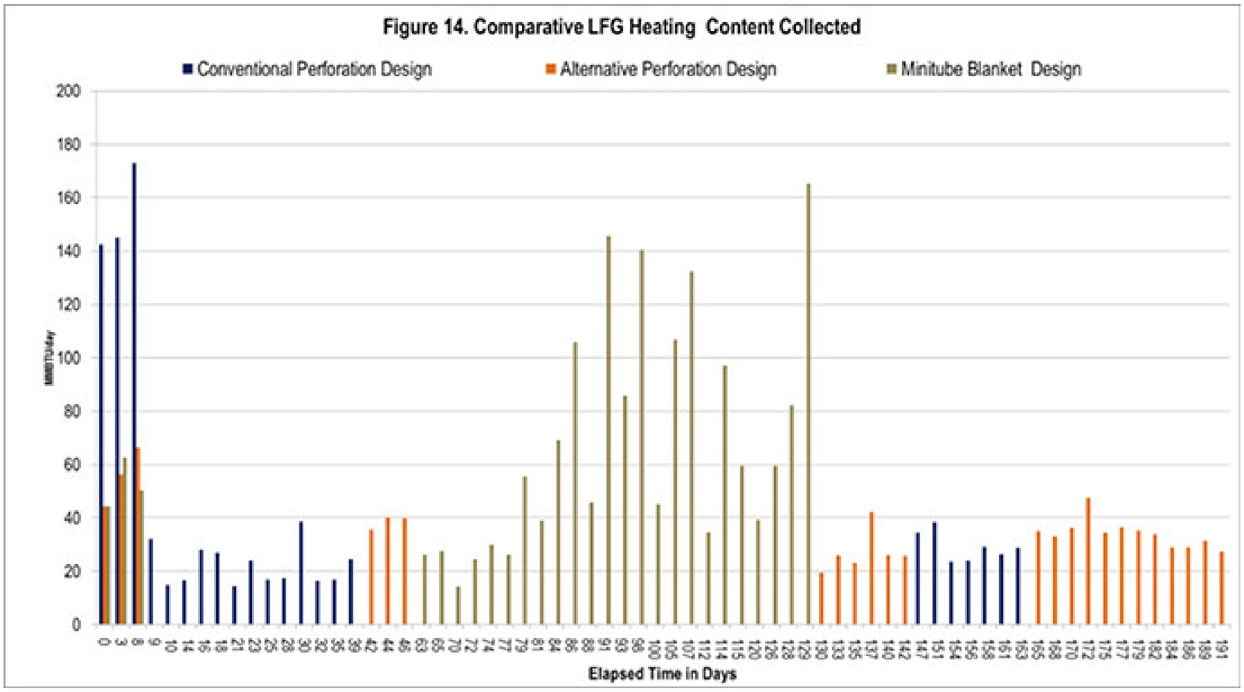


Figure 14. Comparative LFG heating content collected

Summary and Conclusions

The rate at which microbes generate LFG can be best described as diffusive rather than advective, in that LFG generation is a relatively slow process based on a volume of LFG per unit mass of refuse basis. The large volume of LFG generation based on large volume of refuse disposal should not be misunderstood with rapid rate of LFG generation.

If an LFG collection system is designed with excessive flow rates, two undesirable side effects may impact those landfills that covert LFG to renewable energy:

1. The high flow rates lead to excessive air intrusion from areas of landfill with interim cover. These air intrusions in turn cause dilution in CH_4 concentrations as well as inefficiency in conversion of LFG to renewable energy.
2. The corresponding increased number of redundant horizontal and vertical collectors reduces air space utilization for refuse disposal.

LFG collection systems, therefore, should be designed per regulations to collect all of the gas from the entire landfill.

Perforation size of LFG collectors can significantly improve the balance between needed LFG flow rates and needed vacuum ZOI. There really is no significant difference between the Conventional and Minitube-Blanket LFG collectors with respect to dissipation of vacuum ZOI. Even though the relative perforation area of the Conventional LFG collector (11.5 ft.^{2}) was about half of the Alternative LFG collector (4.5 ft.^{2}), both Conventional and Minitube-Blanket LFG collectors had sufficient vacuum at the end of their 700 feet long collector for effective ZOI.

While the alternative LFG collector with the least perforation area (0.01 ft.^{2}) was more successful in preserving the vacuum loss for further reach of ZOI, the small perforation seem to limit its LFG flow rate. For the future studies, either more frequent perforation of 1/8-inch diameter perforation, or slightly larger perforation diameter should be considered for Alternative LFG collector for wider range of LFG capturing rates.

Of the three LFG collectors, the Minitube-Blanket LFG collector presented promising results. With almost half of the perforation area of the Conventional LFG collector, the Minitube-Blanket LFG collector allowed for similar peak collection rate of heating content (165 MMBTU/day) as compared with the Conventional LFG collector (173 MMBTU/day). While the Conventional and Alternative LFG collector perforation design can be modified to improve on their vacuum ZOI and flow rates to collect a higher rate of LFG heating content, both collectors still reduce landfill air space utilization, similarly.

On the contrary, the Minitube-Blanket offers savings in air space utilization. It also offers numerous redundancies due to its frequent and widespread use of corrugated polypropylene pipes, which could offer a more resiliency towards long-term landfill settlement.

The impact of barometric fluctuation on CH_4 emission has been studied for landfills that have chronic CH_4 emissions from interim cover and it is established that a drop of 4 inches in barometric pressure could almost double the rate of CH_4 emission (Xu et al. 2014 and Czepiel et al. 2003). In some cases, an installation of a highly permeable layer, such a shredded tire or gravel, is proposed beneath the landfill interim cover to intercept and mitigate CH_4 emission (Jung, et al. 2011). While at CHRLF, the CH_4 emission is not an issue, the opposite (air intrusion) is of a concern that has caused intermittent inefficiency in LFG to renewable energy conversion. The Minitube-Blanket LFG collector could be a complementary addition to the above-referenced permeable layer to reduce air intrusion significantly.

At CHRLF, the Conventional LFG collectors are spaced 120-foot apart in 30-foot lifts. At this frequency, the construction cost of a Conventional LFG collector is approximately $1.37 per square foot, including material, labor, and installation plus the $130-per-ton cost of air space loss.

At the $1.15-per-square-foot cost for material, labor, and installation, the Minitube-Blanket LFG collector is 16% cheaper than the Conventional LFG collector and saves approximately 75% on air space while covering the same surface refuse area as the Conventional LFG collector.

Therefore, the Minitube-Blanket LFG collector is worth considering for use in the upper lifts of refuse areas, or as integral part of interim cover. The installation cost for the Alternative LFG collector is similar to the Conventional LFG collectors due to common material use. To verify the long-term performance of the Minitube-Blanket as an LFG collector, additional pilot studies are required before using this product in lower lifts of refuse areas to evaluate the long-term operation and maintenance costs as compared with the Conventional LFG collector.

Acknowledgement
The author would like to express his gratitude to CHRLF LFG Lead Wally Grant, as well as LFG crew Jeff Dye, Dean Bell, Jason Parker, and Rusty Bogart for their dedication and support.

References

Bentley, H. W., S. J. Smith, J. Tang, and G. R. Walter. "A method for estimating the rate of landfill gas generation by measurement and analysis of barometric pressure waves." Proceedings of the 18th International Conference on Solid Waste Technology and Management, Philadelphia, PA (2003).

Czepiel, P. M., J. H. Shorter, et al. "The influence of atmospheric pressure on landfill methane emissions." *Waste Management*. 23(7): 593–598 (2003).

El Fadel, M., A. N. Findikakis, and J. O. Leckie. "Numerical modeling of generation and transport of gas and heat in landfills I. Model formulation." *Waste Manag. Res.* 14, 483–504 (1996).

EMCON. *Methane Generation and Recovery from Landfills.* Ann Arbor Science Publishers, Ann Arbor (1980).

Jung, U., P. T. Imhoff, D. Augenstein, and R. Yazdani. "Mitigating methane emissions and air intrusion in heterogeneous landfills with a high permeability layer." *Waste Management*. 31(5):1049–1058 (2011).

Tolaymat, T. M., R. B. Green, G. R. Hater, M. A. Barlaz, P. Black, D. Bronson, and J. Powell. "Evaluation of landfill gas decay constant for municipal solid waste landfills operated as bioreactors." *J. Air Waste Management Association*. 60, 91–97 (2010).

Wintheiser, P. "Improved Horizontal LFG Collection System Performance and Design Based on Field Data." SWANA Symposium (17 March 2014).

Xu, L., X. Lin, et al. "Impact of changes in barometric pressure on landfill methane emission." *Global Biogeochemical Cycles*. 28(7): 679–695 (2014).

Table 1. Vacuum Measurements in Ports Along 800-Foot Trench Using Different Landfill Gas Collector Perforations				
Date	**Vacuum Ports and Stations (Feet)**	**Vacuum Along 800-Foot Trench**		
		Conventional Perforation (Inches of Water Column)	**Alternative Perforation (Inches of Water Column)**	**Minitube-Blanket (Inches of Water Column)**
21-Sep-15	Flow Rate (SCFM)	180	43	59
	Vacuum Source at Port Before Control Valve	22.30	22.50	23.00
	Vacuum at Port After Control Valve	**8.50**	**21.50**	**22.50**
	50	4.50	0.96	1.50
	100	4.00	0.94	1.40
	150	4.00	0.93	1.30
	200	3.90	0.93	1.20
	250	3.50	0.92	1.20
	300	3.40	0.90	1.00
	350	3.20	0.88	0.99
	400	3.10	0.87	0.96
	450	3.00	0.86	0.92
	500	3.00	0.86	0.91
	550	3.00	0.86	0.90
	600	3.00	0.86	0.89
	650	2.90	0.86	0.88
	700	2.90	0.85	0.88
24-Sep-15	Flow Rate (SCFM)	185	70	83
	Vacuum Source at Port Before Control Valve	23.00	23.00	23.00
	Vacuum at Port After Control Valve	**8.50**	**22.00**	**21.50**
	50	4.30	1.30	1.50
	100	4.00	0.96	1.30
	150	3.90	0.94	1.10
	200	3.60	0.92	1.00
	250	3.50	0.91	0.99
	300	3.40	0.90	0.96
	350	3.30	0.89	0.94
	400	3.10	0.88	0.91
	450	3.00	0.87	0.90
	500	3.00	0.86	0.89
	550	3.00	0.86	0.88
	600	2.90	0.85	0.87
	650	2.90	0.84	0.86
	700	2.90	0.83	0.85
29-Sep-15	Flow Rate (SCFM)	218	79	77
	Vacuum Source at Port Before Control Valve	23.50	23.50	23.00
	Vacuum at Port After Control Valve	**9.00**	**21.60**	**21.50**
	50	4.00	0.86	1.50
	100	4.00	0.85	1.40
	150	3.90	0.85	1.30
	200	3.60	0.84	1.10
	250	3.50	0.84	0.99
	300	3.40	0.84	0.97
	350	3.20	0.83	0.93
	400	3.10	0.82	0.90
	450	3.00	0.82	0.89
	500	3.00	0.81	0.88
	550	2.90	0.81	0.88
	600	2.90	0.81	0.87
	650	2.80	0.80	0.86
	700	2.80	0.80	0.85

Table 2. Fixed Gases Monitoring Records From Different Landfill Gas Collector Perforations

Elapsed Time (days)	Date	Conventional Perforation Design							Date	Alternative Perforation Design							Date	Minitube-Blanket Design						
		Fixed Gasses as Measured by Field GEM5000								Fixed Gasses as Measured by Field GEM5000								Fixed Gasses as Measured by Field GEM5000						
		% CH_4	% O_2	% N_2	% CO_2	Temperature (°F)	Landfill Gas Flow Rate (SCFM)	Estimated CH_4 Collected (MMBTU/day)		% CH_4	% O_2	% N_2	% CO_2	Temperature (°F)	Landfill Gas Flow Rate (SCFM)	Estimated CH_4 Collected (MMBTU/day)		% CH_4	% O_2	% N_2	% CO_2	Temperature (°F)	Landfill Gas Flow Rate (SCFM)	Estimated CH_4 Collected (MMBTU/day)
0	9/21/2015	54	1.0	6	39	84	180	142	9/21/2015	56	0.3	4	40	82	43	35	9/21/2015	52	1.1	9	38	77	59	44
3	9/24/2015	54	0.9	7	38	84	185	145	9/24/2015	55	0.3	5	40	82	70	56	9/24/2015	52	1.1	10	38	77	83	63
8	9/29/2015	54	1.1	6	38	82	218	173	9/29/2015	58	0.1	2	34	81	79	66	9/29/2015	**45**	**2.8**	**19**	34	73	77	50
9	9/30/2015	**45**	1.2	**13**	37	82	49	32																
10	10/1/2015	**36**	0.9	**26**	33	83	28	15																
14	10/5/2015	**40**	0.8	**22**	34	82	28	17																
16	10/7/2015	**34**	0.8	**31**	32	72	57	28																
18	10/9/2015	**33**	0.9	**33**	30	80	56	27																
21	10/12/2015	**35**	1.3	**30**	30	78	28	15																
23	10/14/2015	**41**	0.3	**23**	33	78	40	24																
25	10/16/2015	**41**	0.7	**23**	32	81	28	17																
28	10/19/2015	**42**	0.5	**21**	33	80	28	17																
30	10/21/2015	**42**	0.5	**22**	33	80	64	39																
32	10/23/2015	**39**	1.0	**26**	31	78	29	16																
35	10/26/2015	**41**	0.6	**23**	33	74	28	17																
39	10/30/2015	58	0.3	0	38	77	29	25																
42									11/2/2015	58	0.0	0	39	67	42	36								
44									11/4/2015	**47**	0.9	**15**	34	77	58	40								
46									11/6/2015	**43**	0.5	**20**	33	78	64	40								
63																	11/23/2015	**43**	1.2	**20**	33	64	41	26
65																	11/25/2015	**37**	**3.5**	**28**	29	69	51	27
70																	11/30/2015	**34**	**3.5**	**35**	26	66	29	14
72																	12/2/2015	**41**	**2.1**	**25**	30	66	42	25
74																	12/4/2015	**49**	1.9	**16**	32	64	42	30
77																	12/7/2015	59	0	0	41	48	30	26
79																	12/9/2015	63	0	0	37	58	61	55
81																	12/11/2015	62	0.5	0	37	57	43	39
84																	12/14/2015	**45**	0.3	**19**	34	56	106	69
86																	12/16/2015	**45**	0.3	**21**	32	56	161	106
88																	12/18/2015	59	0.3	4	35	57	53	46
91																	12/21/2015	61	0	1	36	54	164	146
93																	12/23/2015	60	0	2	36	53	98	86
98																	12/28/2015	53	0.6	**12**	33	53	182	140
100																	12/30/2015	**42**	0.6	**25**	31	55	75	45
105																	1/4/2016	**45**	0.3	**21**	32	50	162	107
107																	1/6/2016	50	0.7	**15**	33	53	181	132
112																	1/11/2016	**35**	0.9	**34**	29	50	68	35
114																	1/13/2016	51	0.7	**15**	32	52	130	97
115																	1/14/2016	**43**	0.4	**24**	32	52	96	59
120																	1/19/2016	**40**	0.7	**28**	30	53	67	39
126																	1/25/2016	**33**	0.3	**37**	29	54	123	59
128																	1/27/2016	**38**	0.2	**31**	29	64	150	82
129																	1/28/2016	**48**	0	**17**	32	66	235	165
130									1/29/2016	**44**	0.1	**24**	30	55	30	19								
133									2/1/2016	**27**	0.9	**43**	26	72	65	26								
135									2/3/2016	**27**	0.8	**45**	26	58	60	23								
137									2/5/2016	**30**	0.6	**42**	26	58	98	42								
140									2/8/2016	**25**	1.0	**47**	25	68	72	26								
142									2/10/2016	**27**	1.2	**46**	25	57	66	26								
147	2/15/2016	**33**	0.3	**37**	28	59	72	34																
151	2/19/2016	51	0.5	**15**	33	57	52	38																
154	2/22/2016	**28**	0.5	**43**	27	60	59	23																
156	2/24/2016	**28**	1.1	**43**	26	59	59	24																
158	2/26/2016	**28**	1.2	**43**	26	61	71	29																
161	2/29/2016	**25**	0.6	**46**	26	61	71	26																
163	3/2/2016	**27**	0.5	**44**	27	62	73	29																
165									3/4/2016	**29**	0.4	**43**	26	54	84	35								
168									3/7/2016	**29**	0.4	**41**	28	59	78	33								
170									3/9/2016	**30**	0.3	**41**	27	58	84	36								
172									3/11/2016	**44**	0.5	**24**	29	61	74	47								
175									3/14/2016	**35**	0.1	**34**	29	57	67	34								
177									3/16/2016	**30**	0.9	**41**	26	62	84	36								
179									3/18/2016	**29**	0.8	**43**	25	63	84	35								
182									3/21/2016	**32**	0.5	**38**	27	63	72	34								
184									3/23/2016	**25**	1.1	**46**	26	63	78	29								
186									3/25/2016	**25**	1.1	**46**	25	64	78	29								
189									3/28/2016	**26**	0.9	**45**	26	64	84	31								
191									3/30/2016	**26**	0.7	**45**	26	67	72	27								