Albany Interim Landfill Gas Extraction and Mobile Power System

Using Landfill Gas to Produce Electricity

Final Report 97-8
June 1997

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**ALBANY INTERIM LANDFILL
GAS EXTRACTION AND MOBILE POWER SYSTEM
Using Landfill Gas to Produce Electricity**

Final Report

Prepared for

**THE NEW YORK STATE
ENERGY RESEARCH AND DEVELOPMENT AUTHORITY**

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ABSTRACT

The Albany Interim Landfill Gas Extraction and Mobile Power System project served three research objectives: 1) determination of the general efficiency and radius of influence of horizontally placed landfill gas extraction conduits; 2) determination of cost and effectiveness of a hydrogen sulfide gas scrubber utilizing Enviro-Scrub™ liquid reagent; and 3) construction and evaluation of a dual-fuel (landfill gas/diesel) 100 kW mobile power station.

The horizontal gas extraction system was very successful; overall, gas recovery was high and the practical radius of influence of individual extractors was about 50 feet. The hydrogen sulfide scrubber was effective and its use appears feasible at typical hydrogen sulfide concentrations and gas flows. The dual-fuel mobile power station performed dependably and was able to deliver smooth power output under varying load and landfill gas fuel conditions.

Key Words: landfill gas, landfill gas collection, landfill gas energy recovery, landfill gas scrubber, hydrogen sulfide scrubber, dual-fuel engine.

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SUMMARY

The Albany Interim Landfill Gas Extraction and Mobile Power System project, NYSERDA Agreement No. 4276-ERTER-MW-96, was a research project to study the performance and feasibility of three interrelated elements of a landfill gas extraction and energy recovery system. Those elements were: horizontal landfill gas extraction conduits, a landfill gas scrubber for hydrogen sulfide removal, and a dual-fuel (landfill gas/diesel) mobile power generator. Objectives of the research included determination of the overall effectiveness and radius of influence of the gas extraction conduits in the landfill, the cost and efficiency of the hydrogen sulfide (H_2S) scrubber, and operational performance and cost of the dual-fuel mobile power station.

The project clearly indicated the efficiency and effectiveness of constructing horizontal gas extraction conduits in a landfill during normal operation, as opposed to the conventional technology involving construction of vertical wells after landfill closure. Gas extraction from the Albany Interim Landfill is near the theoretical maximum and far above expected extraction rates using conventional technology. The cost of horizontal extraction conduits is much less than the cost of drilling large-diameter vertical wells in solid waste and provides the additional advantage of odor control and energy recovery during the landfill's operational life, rather than having to wait until after closure. The effective radius of influence of the horizontal extraction conduits was found to be about 50 feet; thus, a horizontal pipe-to-pipe separation of about 100 feet appears appropriate. Other factors, including random water movement, channelized flow of gases and odor-control requirements, led to the recommendation that the vertical separation of the horizontal extraction galleries should be about 30 to 50 feet, rather than 100 feet.

The countercurrent liquid-gas contactor scrubber utilizing Enviro-Scrub™ liquid reagent proved successful in dramatically reducing hydrogen sulfide concentrations in fuel gases upstream of the mobile power station. If high concentrations of hydrogen sulfide are present or large quantities of gas must be treated, then the reagent cost may become excessive. The manufacturer, however, has a new reagent regeneration process that may reduce this cost. The reagent consumption is reasonable for gas flows associated with small power production, e.g., 100 kW at the lower hydrogen sulfide concentrations (5 to 200 ppm) typically experienced at landfills.

The dual-fuel 100 kilowatt (kW) mobile power station was capable of smooth operation on a combination of diesel fuel and landfill gas. The control system was tuned to maximize the Btu input from landfill gas and consume only enough diesel fuel to maintain ignition. Initial problems involved control and fuel feed interruptions created by water condensation in various regulators and lines. Adjustment of the heat exchanger to reheat the landfill gas, thus vaporizing aerosol droplets, and the placement of several strategically located dropout tanks along the gas fuel line in the mobile power station solved this problem and it became possible to run the station continuously at full load with maximum landfill gas flow. The control system allowed for load to be dropped or added at will and for the landfill gas to be taken on- or off-line at will, while the mobile power station continued to produce steady power output at the demand level. Cost of power from the mobile power station ranged from about 11 cents to 32 cents per kilowatt hour (kWh) depending upon the power output. Full load levels were more economical than very light loads.

The overall system interacted successfully and it would be possible to utilize any one of the three elements separately at a given landfill site or combine elements as desired. Commercial applications exist for each of the three project elements and the data produced by this research will assist in the application of these technologies.

Section 1

INTRODUCTION

DESCRIPTION OF THE PROBLEM

The production of landfill gases, comprising principally methane, carbon dioxide, and other trace compounds, is a well-known phenomenon. These gases are the key cause of severe odor problems, safety problems due to the flammability and explosive character of the gases, and environmental problems due to the greenhouse effect of the gases. However, these gases can represent an energy resource if properly managed. Existing technology for the capture and utilization of landfill gases involves construction of vertical wells after the capping and closure of the landfill. The disadvantage of the existing practice is that all of the gases which are produced during the operating life of the landfill are lost to the atmosphere, resulting in a loss of potential energy and environmental problems related to odors and greenhouse effect.

A new gas recovery concept has recently been advanced in landfill management. This concept involves the placement of horizontal extraction conduits within the landfill during waste placement. It offers the advantage of landfill gas extraction soon after the conduits are covered with waste rather than having to wait until the final cap has been placed. Various designs of horizontal conduits have been previously employed. These designs involve stone-filled trenches with or without perforated pipes, telescoping arrangements of large- and small-diameter polyvinyl chloride (PVC) or high-density polyethylene (HDPE) pipes, or arrangements involving modular HDPE leaching bed units which have been modified to accept the gravity load imposed by deep placement within waste piles. The key design problem, researched by this project, is the radius of influence of these horizontal extraction elements under various vacuum conditions. Engineers and designers require this data in order to know the proper spacing and location of these elements.

A related major problem experienced during the extraction of landfill gas from cells such as the Albany Interim Landfill involves contamination of the gas by various undesirable chemical compounds, including hydrogen sulfide (H_2S). At the Albany Landfill, hydrogen sulfide has been identified at concentrations as high as 6000 parts per million (ppm), which poses extreme odor problems and renders the gas unusable for energy recovery due to the rapid formation of sulfuric acid in energy recovery equipment. Finding a solution to this problem is very necessary to reduce both inlet hydrogen sulfide concentrations and postcombustion sulfur dioxide emissions.

The third problem addressed by this project involves the inability of small- to medium-sized landfills, such as the Albany Interim Landfill, to effectively produce useful energy from the escaping landfill gas. Traditional engine generator systems require a large capital expenditure for gas conditioning and cleaning and involve the use of dedicated engine generator sets which require a continuous and consistent feed of clean gas at a uniform pressure. These conditions make it feasible to recover energy at larger landfills, where modules of approximately 3.2 megawatts each have been found to be effective. However, smaller landfills are often unable to capture useful energy because of these constraints.

GOALS OF THE PROJECT

The first objective of this project focused on determination of the effective zone or radius of influence in the waste mass surrounding the horizontal gas collectors which were placed in the landfill. It was well established at Albany that the horizontal extractors were successfully removing gas, and it was therefore possible for this system to produce useful design data. The zones of influence were monitored at numerous separate horizontal lines, thus allowing comparison of the data developed for each individual extractor.

As a second major project component, the City of Albany performed the design and installation of a new hydrogen sulfide neutralization technology which had previously been applied only to sewage sludge gasification projects. This technology utilized a liquid chemical known as Enviro-Scrub™, which is marketed by the Quaker Chemical Corporation. The benefits of this reagent are that no precipitate, and therefore no sludge, is formed during the reaction, and the spent reactant is nonhazardous and can be disposed of with the condensate from the landfill gas collection system.

The third goal of the project was demonstration of a new and innovative application of a dual-fuel engine conversion technology which has been previously applied only to diesel/propane engine systems. This dual-fuel conversion of a standard diesel-powered engine generator allowed the dependable operation of electrical generation equipment which, under normal conditions, would continuously consume a minor amount of diesel fuel to maintain ignition while the major energy input was provided by a low-pressure feed of raw landfill gas. As previously stated, removal of hydrogen sulfide is important to reduce engine corrosion due to sulfuric acid. The dual-fuel generation equipment had the advantage that if the landfill gas quality or quantity changed, which is a common experience at small landfills, the power required for energy generation was maintained by automatically increasing the diesel fuel feed to the engine.

FUTURE APPLICATION OF PROJECT RESULTS

The zone of influence data will enable future practitioners to successfully place horizontal collection elements to extract a higher percentage of the landfill gas produced during both the operating and postoperating periods at a cost much lower than that associated with drilling vertical wells in a closed landfill. The environmental benefits, aside from the gain in recovered energy, include elimination of undesirable atmospheric releases of raw gas and attendant odor problems.

The presence of hydrogen sulfide has been a serious problem at landfills in New York and throughout the country. A practical and cost-effective method of small-scale gas scrubbing will enable many landfills to utilize gas which now can only be flared due to hydrogen sulfide contamination. The performance of the system has been verified by testing gas concentrations before and after the reactor vessel and measuring the quantity of reagent required to treat given volumes of gas at known contamination concentrations. The reactor provides a practical solution to a common problem.

The successful operation of the dual-fuel mobile power station will allow future users to confidently install a small landfill gas energy generation unit with the knowledge that the investment is secure against fluctuations in the quantity or quality of landfill gas and that the energy output requirement will be met in any case. The economic benefit involves the use of landfill gas as the major fuel source. This system also results in significant environmental benefits attendant on reduction of raw gas releases to the atmosphere. The potential benefit for future users is considerable because it will now be possible to harness energy from small to medium landfills in a dependable manner. The energy outputs of the dual-fuel engine generator have been measured, as well as diesel fuel consumption rates and landfill gas consumption rates. These results have been summarized to define the benefits of this approach for future users of the system.

Section 2

GENERAL SYSTEM OPERATION

LANDFILL GAS EXTRACTION CONDUITS

The purpose of landfill gas extraction conduits is to allow for removal of anaerobically produced landfill gases during the operating life of a landfill. These elements consist of a relatively permeable channel which is placed at a given horizontal and vertical location in the waste mass, and which is connected to extraction piping which allows for either passive exhausting of the landfill gas or vacuum extraction of the gas. The Albany Interim Landfill has a footprint of approximately 710 feet by 710 feet at the base and has a final elevation of about 80 feet above base elevation. A system of horizontal gas extraction conduits was planned at this landfill as early as 1994, and three different types of gas extraction channels have been installed since that time. A total of 19 horizontal gas extraction conduits now exist at the landfill. The location and specific design details of these conduits are presented in subsequent sections and the interrelationship of the extraction units with the other elements of the project is illustrated in Figure 2-1. Horizontal gas extraction has proven to be extremely successful at this site, and a great deal has been learned regarding the construction, location, and operation of these units.

HYDROGEN SULFIDE SCRUBBER

Landfill gases at the Albany Interim Landfill have exhibited an extremely high concentration of hydrogen sulfide beginning in 1994, peaking during 1995, and with falling concentrations in 1996. These gas concentrations historically measured as high as 12,000 ppm and were at concentrations of about 6,000 ppm during the scrubber testing. These gases create health and safety hazards for landfill workers, an odor nuisance for nearby residents, and have an undesirable environment impact due to greenhouse effect. Moreover, concentrations above about 500 ppm create problems with energy recovery equipment due to the formation of sulfuric acid.

The hydrogen sulfide scrubber evaluated during this project was a cylindrical steel pressure vessel providing a countercurrent liquid-gas contactor system employing a porous media bed within the steel cylinder which allowed downward trickling flow of the liquid reagent over the bed packing. The reagent reacted with the upward-flowing contaminated gases to neutralize the hydrogen sulfide selectively in the gases and produce a cleaned gas stream with very low hydrogen sulfide concentration.

PROJECT COMPONENTS:

- ① PLAN VIEW OF LANDFILL SHOWING CONDUITS.
- ② DUAL FUEL DIESEL/LFG ENGINE WITH 460V., 3 PHASE GENERATOR TO POWER VACUUM BLOWER.
- ③ LFG H₂S PRECLEANING REACTOR UTILIZING NONSLUDGING LIQUID REAGENT. CLEAN GAS REQUIRED FOR DUAL FUEL ENGINE.

FIGURE 2-1

PROJECT SCHEMATIC PLAN

In order to minimize reagent cost, only the gas stream directed to the dual-fuel engine generator was scrubbed. The major gas flow was bypassed to the flare for destruction of the raw gases. Subsequent sections provide design and operating details of the scrubber, which successfully cleaned gases combusted in the dual-fuel engine generator set.

DUAL-FUEL MOBILE POWER STATION

This project evaluated a new and innovative application of a dual-fuel technology applied to a standard Cummins six-cylinder, diesel-powered engine generator set producing 100 kW of electrical power. The mobile power station was fitted to supply either 110-, 230-, or 480-volt, 3-phase power. The dual-fuel system provided electrical power for the 25-horsepower (hp) Lamson blower at the flare station and for the 2-hp Gast blower supplying the engine generator set as well as power requirements of the hydrogen sulfide scrubber. Power production was dependable. No unscheduled down time was experienced in the flare system because during periods when corrective measures were being applied to the landfill gas supply system, the engine generator was run on diesel fuel, providing a stable power supply for the gas extraction and combustion system, which operated 24 hours a day, seven days a week, for 13 months.

Landfill gas quality and quantity changes are a common experience at small and medium landfills. This system maintained uninterrupted power output by automatically varying the diesel fuel to the engine. Details concerning the general arrangement of the dual-fuel engine generator unit are provided in subsequent sections.

Section 3

LANDFILL GAS EXTRACTION UNITS

TIRE-FILLED EXTRACTORS

Three types of horizontal Landfill gas collectors have been installed in the Albany Interim Landfill. The tire-filled (Type A) design (see Figure 3-1) consists of a series of 10-foot lengths of schedule 80 PVC piping of 6-inch and 10-inch internal diameters (IDs). This piping is laid over the landfill surface such that approximately 2 feet of the 6-inch ID pipe is inserted into the 10-inch ID pipe. The gap created between the outside of the 6-inch ID pipe and the inside of the 10-inch ID pipe provides a void in which the landfill gas can be extracted. To enlarge the surrounding void space and to enhance the connection to the landfill's interstitial spaces, rubber tires of various sizes are installed around the piping. A rectangular-shaped grid geonet is then draped over the top of the tires and piping to ensure that no landfill matter blocks the gap between the 6-inch and 10-inch ID pipes. The tires and piping are then buried in the landfill materials.

STONE-FILLED EXTRACTORS

The stone-filled (Type B) horizontal landfill gas collectors (see Figure 3-2) consist of 20-foot lengths of 4-inch ID Hancor HI-Q perforated pipe. The pipe lengths are connected together by 4-inch ID Hancor HI-Q couplings. To counteract differential settlement which may cause the pipe to become separated at the joints, a 3-foot length of 6-inch ID Hancor HI-Q piping is slipped over the joints. It is anticipated that the overlap should allow gas flow in the conduit to continue even if the conduit becomes separated at the joint. Perforated schedule 40 PVC pipe was also used in certain conduits.

The horizontal landfill gas collector pipe is inserted into a trench within the landfill that is backfilled with No. 2 crushed stone. The stone medium is very permeable, allowing landfill gas to enter the pipe through the perforations. A filter fabric is installed in the bottom of the trench and wrapped around the stone to ensure that the stone does not become contaminated with landfill material. The pipe and stone backfill are then buried with landfill material.

The last 20 feet of this pipe is not backfilled with stone. Instead, a 20-foot length of 6-inch ID schedule 80 PVC is inserted over the 4-inch ID pipe. The PVC pipe daylights approximately 3 feet from the side slope of the landfill. The landfill gas is extracted from the end of this pipe.

TYPE A TIRE-FILLED EXTRACTORS
FIGURE 3-1
NOT TO SCALE

FIGURE 3-2
TYPE B STONE-FILLED EXTRACTORS
 NOT TO SCALE

HDPE INFILTRATION CHAMBERS

The Type C design employs a prefabricated modular plastic unit, the "Infiltrator™" (shown on Figure 3-3), as a dome-like structural raceway for receipt and transmission of landfill gas. The gas is extracted from two 4-inch schedule 80 pipes extending from the raceway to the exterior of the landfill. Thin-wall perforated pipes are also placed within the units for selective extraction.

Prefabricated H-10 strength units are laid along a level waste surface and fitted with structural reinforcing columns and bottom straps. The reinforced units are then covered with shredded waste as a protective layer. The design and details of the units are intended to allow movements associated with subsequent settling and loading conditions. Although gas was successfully extracted from the Type C conduits, further research will be required to perfect this system and prevent upward intrusion of waste into the open channel face.

EFFECTIVE ZONE OF INFLUENCE

The horizontal and vertical placement of gas extractors at Albany Interim Landfill is illustrated schematically in Figures 3-4 and 3-5. All extractors above the +10-foot elevation level are Type C. The precise surveyed locations of the extraction conduit outlet points are shown in plan and elevation in Appendix 2.

Total gas extraction for the entire system compares very favorably with predicted gas generation curves. Figure 3-6 illustrates the predicted landfill gas recovery vs. time curve. The average recovered flow rate in September 1996 of 650 standard cubic feet per minute (SCFM) is well above the expected range of gas recovery and is surprisingly near the maximum theoretical gas production. Additional extraction lines and system adjustments increased the flow to over 800 SCFM in November 1996. This extremely favorable performance validates the general effectiveness of horizontal gas extraction practiced during active landfill operation. Also, the high gas production is thought to be related to the practice of waste shredding at this landfill.

Municipal solid waste is an extremely heterogeneous material and, therefore, it is not a mathematically uniform porous media producing mathematically uniform zones of influence around the gas extraction conduits. The evaluation and practical determination of an effective zone of influence to guide the location and spatial placement of horizontal gas extractors is a complicated endeavor which must include reference to common sense and operational realities. In addition to the heterogeneity of the

FIGURE 3-3
HDPE EXTRACTION CHAMBERS (TYPE C)
NOT TO SCALE

3-6

FIGURE 3-4
LFG EXTRACTOR PLAN AT ELEV. +10 FEET
NOT TO SCALE

FIGURE 3-5

LFG EXTRACTOR GENERAL ARRANGEMENT

NOT TO SCALE

FIGURE 3-6
LANDFILL GAS RECOVERY vs: TIME

waste substrate itself, biophysical changes of the waste over time and the movement of water influence the effectiveness of gas extraction systems. Furthermore, the type of waste placed, such as C & D waste, sludges, municipal waste, and whether or not the waste is shredded, are important variables. Finally, the existence and quality of the landfill liner and landfill cap are critical to evaluation of gas extractor performance. These membranes retain the biogas, reduce the opportunity for air intrusion and effectively extend the radius of influence. Given the complicated and dynamic character of the set of variables which must be considered for a practical solution, the observations of this project must be considered as practical guidelines for future activities rather than precise limiting values.

The data initially gathered during the summer of 1996 was analyzed and produced rather confusing results stemming from the fact that no cap was in place and from the fact (indicated by pipeline TV inspection) that certain of the type C extraction conduits had failed due to the intrusion of waste mass pushing up through the bottom straps of the structures. During the fall of 1996, a cap was placed over a large portion of the landfill and effective valve connections were made to all of the extractors in place, thus enabling a set of data to be collected in November 1996, which produced useful results for determining the effective zone of influence of the horizontal conduits. A detailed graphic presentation of these data is found in Appendix 1, along with a legend of the events portrayed on the graphs.

Pressure measurements were taken in adjacent extractors with a Landtec GEM 500 landfill gas meter. At a radius of 50 feet from a single vacuum extractor, the static pressure in the waste mass was observed to drop from positive pressure to a zero value. This indicates that the optimum placement for horizontal extractors at typical system vacuum pressures in waste similar to that placed in Albany is approximately 100-foot separations. The 50-foot radius of influence (yielding a 100-foot distance from pipe to pipe) would theoretically apply in both the horizontal and vertical planes; however, our practical experience at the landfill suggested that the best course of action is to utilize the leachate collection system for a bottom gas collector network, then place a series of horizontal collectors at an elevation about 30 feet above bottom grade (to avoid waterlog conditions), and then to place a staggered array of horizontal collectors at 30-foot to 50-foot vertical elevation stages in order to maximize collection efficiency and minimize the emission of raw gas through channels which might not behave according to uniform influence models. Figure 3-6 illustrates the conceptual layout of horizontal gas extraction in a typical landfill cell.

If the waste at a given landfill is much less dense than the shredded material placed in Albany, then the spacing could theoretically be wider; however, our experience with the unpredictable channelization of gas flows indicates that it would be more prudent to space the extractors closer together than indicated

FIGURE 3-7
HORIZONTAL LFG EXTRACTION CONCEPT PLAN
 NOT TO SCALE

based on the data, in order to maximize gas collection and minimize odor emissions. The low cost of horizontal gas collectors relative to vertical drilled wells allows for this additional conduit placement.

Table 3-1 provides typical landfill gas quality and flow rate information. This data was recorded on November 14, 1996, after the drawdown tests as reported in Appendix 1.

Table 3-1
TYPICAL LANDFILL GAS QUALITY AND FLOW RATE
(Data from November 14, 1996)

<u>Location</u>	<u>CH₄</u>	<u>CO₂</u>	<u>O₂</u>	<u>BAL</u>	<u>PRESSURE (WG)</u>	<u>FLOW (SCFM)</u>
Combined East (E 901)	51.4	42.9	1.0	4.7	-28.0	326
Combined West (W 900)	56.4	39.3	1.1	3.2	-27.4	350
Flare (B 903)	54.9	40.7	0.6	3.8	+56.7	676

ECONOMICS

The approximate cost (including labor and materials) of the three different types of gas extraction units used at Albany are as follows: tire-filled extractors, \$12 per lineal foot (not including tire/tip fee income); stone-filled extractors, \$14 per lineal foot, HDPE infiltration chambers, \$16 per lineal foot. Work is currently ongoing to combine elements of the stone and tire design to improve gas extraction performance and reduce cost. The higher cost of HDPE chambers may be justified in cases where leachate injection is a primary objective.

These costs may be compared with typical vertical drilled well costs reported at \$70 to \$80 per installed lineal foot. Assuming that similar collection efficiencies per lineal foot of conduit can be experienced with horizontal and vertical elements (this is supported by the high collection efficiency experience at Albany), it is apparent that there are great savings associated with the installation of horizontal gas extraction systems during landfill operations as compared with drilling a similar array of vertical wells after the landfill is closed. Additional economic benefits include the ability to recover energy from the gas during landfill operation and reduction of costs associated with odor complaints during landfill operation.

Section 4

HYDROGEN SULFIDE SCRUBBER

DESCRIPTION

The hydrogen sulfide scrubber constructed for this project is a steel pressure vessel countercurrent liquid-gas contactor. As shown in Figure 4-1, the principal elements of the reactor are a reagent reservoir at the bottom, a porous media trickling bed for the contact reaction in the center of the vessel, and a wire gauze demister to remove liquid droplets from the clean gas at the top of the vessel above the reagent distribution level. The scrubber is sized to handle up to 200 SCFM; however, typically the energy requirements of the dual-fuel engine generator ranged from 15 to 40 SCFM. Thus, the unit had adequate capacity for the service flow rates and easily handled the required turndown ratio.

The contaminated gas enters an inlet port about 2 feet above base level and the gas flows in an upward direction through a packed bed section, while the liquid reagent trickles downward. The chemical reaction is facilitated by the very large surface area of the plastic packing media. The spent reagent is disposed together with the landfill leachate. Reaction byproducts include water and a nonhazardous water soluble compound, dithiazine.

All components are of mild steel construction except for the stainless steel wire gauze elements of the demister section. Probably future units could be built with less expensive, lighter-weight plastic components because of the low pressures involved in this type of scrubbing operation. The inlet gas pressures at the dual-fuel control system were typically in the 20- to 40-inches water column range, and the pressure drop through the scrubber was about 4- to 6-inches water column.

PERFORMANCE RESULTS

Scrubbing results were excellent and it was easily possible to obtain removals in the 98 and 99 percent brackets even for high inlet concentrations. At lower inlet concentrations, between 500 and 1,000 ppm, it was easily able to maintain zero outlet concentrations. Table 4-1 and Figure 4-2 illustrate typical scrubber performance at elevated inlet concentrations. At reduced inlet concentrations, the run time for each reagent reservoir quantity was proportionately lengthened and the H_2S concentration was typically zero during the middle portions of the run.

Table 4-1

ENVIRO-SCRUB PERFORMANCE DEMONSTRATION

Location: Albany Landfill; Albany, New York
 Product: Enviro-Scrub

Gas Flow (scfm) 200
 Inlet H₂S, ppm 6000

<u>Sample Time</u>	<u>Run Time</u>	<u>H₂S Conc. (Outlet)</u>	<u>% Removed</u>
12:55 PM	00:00	6000	0.0%
12:58 PM	00:03	600	90.0%
01:15 PM	00:20	100	98.3%
01:45 PM	00:50	90	98.5%
02:00 PM	01:05	60	99.0%
02:20 PM	01:25	45	99.3%
02:30 PM	01:35	60	99.0%
03:15 PM	02:20	80	98.7%
03:45 PM	02:50	90	98.5%
04:15 PM	03:20	80	98.7%
04:35 PM	03:40	200	96.7%
04:45 PM	03:50	400	93.3%
05:00 PM	04:05	425	92.9%
05:10 PM	04:15	500	91.7%

ECONOMICS

The cost of the liquid reagent is the important element of the economic analysis for H₂S removal; the construction cost of the scrubber vessel (for small scale systems such as this one) was not a dominant factor, being in the range of \$5,000 to \$10,000.

In general, the reagent consumption for a zero outlet concentration is approximately 0.075 gallon per ppm H₂S removed per million standard cubic feet treated. The cost of the reagent ranges from \$7 to \$10 per gallon based upon quantity ordered.

Internal combustion engines generally have an intake limit of about 500 ppm H₂S; therefore, the performance demonstration was run until the breakthrough equaled this concentration. At the conditions prevailing during this demonstration (6,000 ppm H₂S, 200 SCFM), a 12-gallon reservoir of reagent lasted about 4 hours and 15 minutes.

FIGURE 4-1

HYDROGEN SULFIDE SCRUBBER NOT TO SCALE

FIGURE 4-2
HYDROGEN SULFIDE REMOVAL

The landfill gas consumption of the engine generator at low load (our typical load was about 20-25 kW) averaged about 20 SCFM; therefore, the 12-gallon reservoir would last 3 to 4 days, at a cost of about \$120. As the inlet concentrations fell, the reagent consumption fell proportionately.

The manufacturer of the reagent, Quaker Chemical Corporation, reports that a new regeneration technique can substantially reduce reagent costs. This regeneration technology may be very beneficial for high reagent consumption applications.

Section 5

DUAL-FUEL MOBILE POWER STATION

DESCRIPTION

The dual-fuel mobile power station was housed inside an insulated stainless steel semi-trailer, 35 feet in length, having two side-access doors and a rear roll-up door. This trailer allowed for effective temperature and weather control, while muffling engine noises. The major components of the mobile power station, as illustrated in Figure 5-1, include a Cummins diesel-driven generator set manufactured by Martin Machinery, Model MCD-100, rated at 100 kW continuous and 135 kW standby, at 277-480 volts, 3-phase, 151 amps. The system is operated at 60 Hz. and 1800 rpm. A diesel fuel tank is located within the mobile power station, as well as necessary electrical circuitry and switching gear to allow for power output at either 110, 230, or 480 volts, 3-phase.

The landfill gas fuel first travels through an engine exhaust heat exchanger to raise the temperature of the landfill gas to approximately 120°F., thus revaporizing some of the small water condensation droplets. The gas then enters the dual-fuel feed system, which has been augmented with several strategically located condensate dropout boxes. A radiator hot-air plenum allows for the engine radiator exhaust to be conducted out of an opening in the front end of the trailer. Engine exhaust exists at two locations, before and after the heat exchanger, through the ceiling of the trailer. Combustion air enters through inlets both through the ceiling and the rear floor area of the mobile power station.

The key innovation developed during this project was the assembly of components into a working arrangement that allowed for automatic dual-fuel adjustments, maximizing Btu input from the landfill gas but compensating for any required power by adding additional diesel fuel. A minimum amount of diesel fuel was constantly fed to the engine to maintain ignition (this was a true diesel engine and so would not operate on gas only, without spark plugs) and provide additional lubrication to the head and valve areas. A Barber Coleman electronic diesel fuel governor was mated with a proprietary dual-fuel gas control system provided by Alternate Energy Corporation (Providence, Rhode Island) in a manner which accomplished these goals.

Initial problems included difficulties created by condensation of water in various regulators and control points and in fuel lines prior to the induction of the landfill gas just upstream of the turbocharger. These problems were corrected by the addition of strategically located condensate pressure dropout

FIGURE 5-1
**DUAL FUEL MOBILE POWER STATION
 GENERAL ARRANGEMENT**

tanks and proper sloping of lines to allow a flow of liquid to these tanks. Normal startup difficulties with control coordination and electrical systems were encountered and corrected as the work proceeded.

The ultimate operation of the system provided for a very smooth power output consuming a combination of diesel and landfill gas fuels. Automatic balancing of the necessary fuels was accomplished while maximizing Btu input by landfill gas. The load could vary from zero to 100 kW and be stepped up or down at will. During these load changes, the fuel system automatically compensated for the engine energy requirements and provided sufficient landfill gas with a balancing quantity of diesel fuel to maintain a smooth and stable power output. Exhaust gas temperature (EGT) is an important parameter to monitor because it tends to rise as the landfill gas ratio is increased. Excessive EGT can cause engine damage.

Table 5-1 summarizes the typical performance experienced with the dual-fuel mobile power station under various load and fuel conditions.

Table 5-1
DUAL-FUEL MOBILE POWER STATION
PERFORMANCE RESULTS

Typical Performance During Sept. 1996 Trials

All Values at 60 Hz., 480 volts

Landfill Gas Quality: approximately 52% CH₄

Energy Output (kW)	Diesel Fuel Flow (GPH)	Approximate LFG Flow (SCFM)	Percent Reduction of Diesel Fuel
25	2.1	0	0
25	1.0	12	52
40	2.75	0	0
40	1.0	15	63
65	4.2	0	0
65	1.0	24	76
85	5.75	0	0
85	1.5	24	74
100	7.0	0	0
100	2.1	26	70

ECONOMICS

Costs of items included in the mobile power station as constructed at Albany were as follows:

• Insulated semi-trailer (used)	\$ 14,000
• MCD-100 engine generator set	15,000
• AEC dual-fuel control system	4,000
• SAF-T-NET gas monitor	2,100
• Diesel fuel tank and governor system	1,300
• Electrical controls distribution and wiring	6,200
• Heat exchanger	1,700
• Condensate dropouts	600
• General fittings & miscellaneous parts	500
• Assembly labor	<u>11,000</u>
TOTAL CAPITAL COST	\$ 56,400

Assuming an economic life of the mobile power station of 5 years and an interest rate of 8%, annual amortization cost equals \$14,126. For our economic analysis, we assume that off-road diesel fuel cost is \$1 per gallon, and that no cost is associated with the landfill gas fuel because installation of landfill gas conduits and vents is generally required, even if the gas is merely flared for odor control. Annual O & M costs are assumed to be 20% of capital for low output, 35% of capital for medium output, and 50% of capital for high output. Part-time operator attention is \$100 per day. Hydrogen sulfide removal costs are not included below because the need for and cost of scrubbing is site specific.

Table 5-2 summarizes the cost of energy produced by the mobile power station under various power output levels.

Table 5-2

DUAL-FUEL MOBILE POWER STATION ECONOMIC SUMMARY WITH MAXIMUM LANDFILL GAS

<u>Continuous Power Output (kW)</u>	<u>Diesel Fuel Required (gal/day)</u>	<u>Amortization, Fuel & O&M Cost (\$/da)</u>	<u>Energy Cost (\$/kWh)</u>
25	24	194	0.32
40	24	194	0.20
65	24	209	0.13
85	36	221	0.11
100	50	266	0.11

Section 6

CONCLUSIONS AND RECOMMENDATIONS

LANDFILL GAS EXTRACTION UNITS

- Horizontal extraction of landfill gas is an extremely effective and economical means of retrieving energy and reducing odors during landfill operation. The useful life of the extractors continues after closure of the landfill.
- Several types of extractors are feasible and practical, including tire-filled conduits, stone-filled conduits, and reinforced, prefabricated modular chambers. Further design work and experimentation will be required to perfect the design of the prefabricated modular units, which are more expensive, but appear useful for leachate injection.
- The radius of influence of horizontal extraction conduits under normal vacuum pressures was about 50 feet in the waste mass at the Albany Landfill. It is important to realize that Albany utilized shredded, wetted municipal solid waste and conventionally placed waste may be more porous and would theoretically allow wider spacing of conduits. However, the heterogeneous nature of waste and the tendency of the gas to channelize along unpredictable lines indicate that a conservative design would utilize a 50-foot radius of influence (100-foot separation intervals) horizontally, with staggered layers at about 30-foot to 50-foot vertical intervals.
- Gas extractors placed too near the bottom of the landfill are subject to waterlogging from buildup of leachate above the liner.
- Horizontal extractor units located too near the surface in uncapped areas are subject to massive air intrusions when placed under vacuum pressure. The upper extractors should be covered with 20 to 30 feet of waste if operated prior to capping.

HYDROGEN SULFIDE SCRUBBER

- A simple cylindrical countercurrent liquid gas contactor scrubber can very effectively remove hydrogen sulfide from landfill gases utilizing the Enviro-Scrub™ reagent.

- At very high H_2S concentrations and high flow rates, the economics of this system must be carefully evaluated due to high cost of the reagent; new techniques to regenerate the liquid reagent may be appropriate in these cases and may help reduce cost.
- For relatively low concentrations (e.g., less than 1,000 ppm H_2S) and at the relatively low flow rates required for small power plants such as the mobile power station, this technology is economically feasible to reduce the H_2S concentrations to levels compatible with equipment maintenance requirements.

DUAL-FUEL MOBILE POWER STATION

- The use of landfill gas together with diesel fuel in a conventional diesel power generator set was found to be extremely practical and operated very satisfactorily.
- The combination of a commercially available electronic diesel fuel controller mated with a commercially available dual-fuel system provided smooth control of fuel ratios during changing power demands and changing landfill gas availability scenarios.
- The estimated cost of electric power from the demonstration unit varied between 32¢ per kWh and 11¢ per kWh, depending on output load. Higher loads were more economical.
- The dual-fuel mobile power station concept may prove extremely feasible in situations where normal power supplies are unavailable or expensive to install, but a small-scale power requirement exists at particular locations on a landfill site. Operation of leachate pumps or landfill gas flare equipment would be typical examples of such requirements.

APPENDICES

APPENDIX 1

The graphs in Appendix 1 illustrate the Static Pressure and Methane Concentration curves for all active extraction points monitored during the following sequence of events:

SYSTEM STATUS LEGEND

- 1) Normal gas extraction operation, all valves open to negative pressure from flare blower; then:
- 2) All valves closed for a period of 24 hours; then:
- 3) Extraction conduits ALBE0002 and ALBW002 open 2 hours; all other closed
- 4) Extraction conduits ALBE0002 and ALBW002 open 4 hours; all others closed
- 5) Extraction conduits ALBE0002 and ALBW002 open 6 hours; all others closed
- 6) Extraction conduits ALBE0002 and ALBW002 open 20 hours; all other closed; then:
- 7) Extraction conduits ALBE001A, ALBE0002, ALBE0003 and ALBW001, ALBW002, ALBW003 open 24 hours; all others closed; then:
- 8) Normal gas extraction operation, all valves open 24 hours to negative pressure from flare blower

LANDFILL GAS PRESSURE AND METHANE CONCENTRATION

CONDUIT: ALBE001A

A-3

LANDFILL GAS PRESSURE AND METHANE CONCENTRATION

CONDUIT: ALBE0002

LANDFILL GAS PRESSURE AND METHANE CONCENTRATION

CONDUIT: ALBE0003

LANDFILL GAS PRESSURE AND METHANE CONCENTRATION

CONDUIT: ALBE004A

LANDFILL GAS PRESSURE AND METHANE CONCENTRATION

CONDUIT: ALBE005C

LANDFILL GAS PRESSURE AND METHANE CONCENTRATION

CONDUIT: ALBE006C

LANDFILL GAS PRESSURE AND METHANE CONCENTRATION

CONDUIT: ALBE007C

A-9

PRESSURE
(INCHES H₂O)

A1-7

LANDFILL GAS PRESSURE AND METHANE CONCENTRATION

CONDUIT: ALBE010C

LANDFILL GAS PRESSURE AND METHANE CONCENTRATION

CONDUIT: ALBE011C

A-11

LANDFILL GAS PRESSURE AND METHANE CONCENTRATION

CONDUIT: ALBW0001

LANDFILL GAS PRESSURE AND METHANE CONCENTRATION

CONDUIT: ALBW0002

LANDFILL GAS PRESSURE AND METHANE CONCENTRATION

CONDUIT: ALBW0003

A-14

LANDFILL GAS PRESSURE AND METHANE CONCENTRATION

CONDUIT: ALBW04AC

LANDFILL GAS PRESSURE AND METHANE CONCENTRATION

CONDUIT: ALBW05AC

LANDFILL GAS PRESSURE AND METHANE CONCENTRATION

CONDUIT: ALBW06AC

LANDFILL GAS PRESSURE AND METHANE CONCENTRATION

CONDUIT: ALBW07AC

A-18

PRESSURE
(INCHES H₂O)

— Static Pressure
- - - CH₄ Concentration

METHANE
CONCENTRATION
(PERCENT)

LANDFILL GAS PRESSURE AND METHANE CONCENTRATION

CONDUIT: ALBW10AC

A-19

PRESSURE
(INCHES H₂O)

LANDFILL GAS PRESSURE AND METHANE CONCENTRATION

CONDUIT: ALBW11AC

APPENDIX 2

SURVEY MAPS OF EXTRACTOR LOCATIONS

A2-1 West Gas Vent Locations - Plan View

A2-2 West Gas Vent Locations - Profile

A2-3 East Gas Vent Locations - Plan View

A2-4 East Gas Vent Locations - Profile

WEST GAS VENT LOCATIONS - PLAN VIEW

FIGURE A2-1

WEST GAS VENT LOCATIONS - PROFILE

FIGURE A2-2

EAST GAS VENT LOCATIONS - PLAN VIEW

FIGURE A2-3

EAST GAS VENT LOCATIONS - PROFILE

FIGURE A2-4