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METHANE RECOVERY FROM LANDFILLS

A field testing program was recently completed at the Kenilworth and Oxon Cove landfills in the District of Columbia to determine if they contain enough methane to warrant recovery and use as a fuel source. Probes and wells were installed, gas samples were analyzed during static and pumping conditions, and pressures and temperatures were monitored. The results indicate favorable conditions for the recovery and use of the landfill gas.

INTRODUCTION

The energy potential of methane gas generated in landfills was not realized until the early 1970's. The first commercial use was at the Palos Verdes landfill in June 1975. Currently, 10 gas recovery facilities, eight in California, one in Illinois, and one in New Jersey, are in commercial operation, with designed extraction rates ranging between 0.5 and 8 million cubic feet of gas per day. Numerous testing programs are in various stages of completion throughout the country. (APL has prepared the *Landfill Methane Utilization Technology Workbook,*[1] which summarizes the 10 on-line projects and includes information on gas generation and processing and environmental, economic, and legal considerations.)

Landfill gas is typically almost entirely methane and carbon dioxide, although trace amounts of many other compounds may be present. Methane is produced by anaerobic digestion of the organic solid wastes. It is flammable, colorless, odorless, and tasteless and is the major constituent of natural gas. The raw gas generally has a heating value of about 500 Btu per cubic foot (half that of natural gas). A typical landfill can be expected to generate gas at varying rates for at least 40 years. However, while anaerobic digestion is quite well understood, the lack of control over the production-rate-governing variables (solid waste composition, oxygen concentration, moisture content, nutrients, pH, and temperature) in actual landfills makes the prediction of gas generation uncertain unless extensive field testing programs are conducted. Computer simulation efforts are being conducted at APL and elsewhere to model gas generation under specific site conditions in order to provide more reliable estimates of a landfill's gas recovery potential.

For economical gas recovery, a landfill should have a minimum depth of 30 to 40 feet and at least a million tons of waste in place. There are more than 1000 such landfills in the U.S. that could support recovery and utilization systems.

Development begins with a field testing program that is followed by a market evaluation and then by the design of collection, processing, transport, and utilization/conversion systems. APL has studied the technology of landfill gas recovery and utilization as an energy resource since 1977. Because very little equipment is specifically designed for analyzing landfill gas, we are developing field testing techniques to provide accurate methods that will shorten the length of future testing programs. We have instrumented a mobile testing laboratory to measure gas composition, temperature, pressure, and withdrawal rate.

We will describe a recently completed field testing study for the National Capital Region of the National Park Service at the Kenilworth and Oxon Cove landfills to determine the feasibility of recovery and use of the gas. Both the quantity and quality of the gas must be acceptable for its intended uses.

The planned use of the gas at the Kenilworth landfill is for space heating and electricity at the Kenilworth greenhouses. At the Oxon Cove landfill, no specific use of the gas has yet been developed, although a small percentage may supply the space heating and electricity at the Oxon Hill Farm.

LANDFILL SITES

The low-lying area on the east bank of the Anacostia River at Kenilworth in Northeast Washington, D.C., was the site of a burning landfill from 1942 to 1968, followed by sanitary landfill operations to dispose of the District of Columbia's wastes from February 1968 until its closing in January 1970. At that time, the Kenilworth landfill contained approximately 0.5 million tons of raw refuse, 1.4 million tons of incinerator ash, and 2.2 million tons of burned residue. The landfill has an average depth of 25 feet and covers an area of about 145 acres.[2] It was covered by 3 feet of soil combined with 50,000 cubic yards of sewage sludge to aid in developing the grass turf on the completed landfill.[3] The landfill area is now Kenilworth Park with several picnic and playfield areas, tennis courts, comfort stations, and an exercise course.

Before the Kenilworth landfill was closed, landfilling operations began (on October 15, 1969) at Oxon Cove, located on the Washington-Prince George's

County line near the Oxon Hill Farm. In two years, 1,500,000 tons of raw refuse and 275,000 tons of incinerator ash were landfilled, covering 140 acres to an average depth of 30 feet.[3,4]

FIELD TESTING PROCEDURES

APL installed probes (in 4-inch-diameter bore holes) and test wells (in 9-inch-diameter bore holes) at Kenilworth and Oxon Cove. Drilling of the bore holes provided important information on depth of the cover material, depth and types of fill, and depth of the water table.

At the Kenilworth landfill, drilling at 24 locations to a maximum depth of 40 feet revealed cover material thicknesses between 3 and 6 feet, with an average depth of 3.5 feet. Incinerator ash was present in over half of the locations and raw refuse was found at only seven locations. Water was found at approximately half of the locations at depths from 8 to 32 feet. At the Oxon Cove landfill, the cover material depth ranged from 2 to 16 feet and averaged 9 feet at the 15 drilling locations. Raw refuse was present at all locations except one where incinerator ash was found. Water was found at five locations at depths ranging from 20 to 40 feet.

Fifteen test probes were installed at Kenilworth and eight at Oxon Cove. They consisted of quarter-inch-diameter polyflow polyethylene tubing encased in 1-inch-diameter polyvinyl chloride (PVC) pipe, ranging from 6 to 22 feet in length (Fig. 1). The polyethylene tubing runs from a rubber stopper near the surface, down the length of the probe, through another rubber stopper, and into a perforated section of pipe 1 to 2 feet in length. Some of the longer probes were equipped with a second length of polyethylene tubing, and a second set of perforations, located approximately half way down the PVC pipe, permitted testing at two depths. The bore holes were backfilled with gravel and then sealed with a few feet of compacted cover material.

The probes were initially used to obtain estimates of the quality of gas present at various locations. Gas samples were collected and analyzed by gas chromatography for methane, carbon dioxide, nitrogen, oxygen, and hydrogen. The methane gas concentration and bore hole composition data were used to determine the location of the larger test wells.

Sixteen test wells were installed, nine at Kenilworth and seven at Oxon Cove. The test wells were constructed with 3-inch-diameter PVC pipe as shown in Fig. 2. The pipe ranged in length from 8 to 20 feet with the lower 5 feet slotted. The pipes were capped on the lower end and equipped with a removable plug at the top. The bore holes were backfilled with gravel to a few feet below the surface and then backfilled with compacted cover material. The wells used for pumping tests were furnished with an additional seal of approximately 1 foot of concrete. The tops of the wells were enclosed in a box, allowing for easy access.

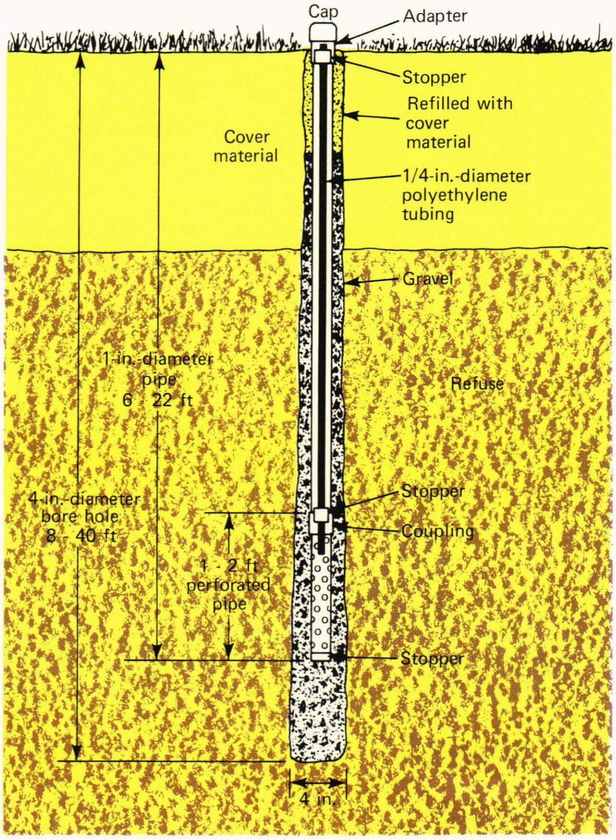

Fig. 1—Twenty-three test probes, designed using 1-inch-diameter PVC pipe, were installed in 4-inch-diameter bore holes in the landfills. Landfill gas was sampled from the perforated section of the pipe through the polyethylene tubing.

Static Testing

Static landfill gas samples were collected in evacuated carbon-steel cylinders from the test probes and test wells and returned to APL for analysis with a two-column gas chromatograph to determine each component quantitatively.

Besides the collection of samples for laboratory analysis, field gas analysis was also performed using a nondispersive infrared analyzer to measure the concentrations of carbon dioxide and methane. A portable indicator was used to detect the presence of oxygen. The field results, although not as accurate, corresponded quite well with the laboratory results and provided valuable on-the-spot data. Temperature and pressure data were also collected.

At the Kenilworth landfill, methane concentrations as high as 98% by volume were found. The balance of the landfill gas was generally carbon dioxide and/or nitrogen. The average methane and carbon dioxide concentrations for each location, shown in Fig. 3, indicate two regions of the landfill with high methane concentrations that correspond to areas where the bore holes had been drilled through raw refuse. (The bore hole composition in other areas consisted mostly of ash.) The high methane concentration at Kenilworth is unusual. It is expected that

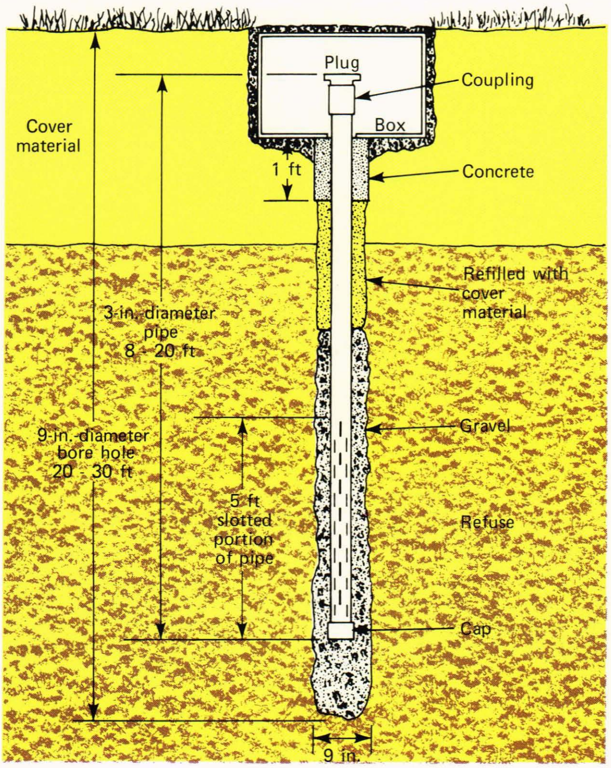

Fig. 2—Sixteen test wells, constructed from 3-inch-diameter PVC pipe, were installed in 9-inch-diameter bore holes in the landfill. Wells used for pumping tests were sealed with concrete, and a box was used to encase the wellhead to allow for easier access for gas sampling.

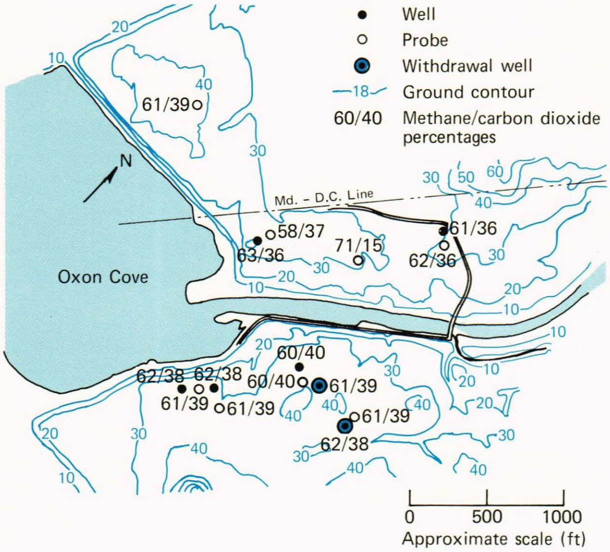

Fig. 4—Shown are the average methane and carbon dioxide concentrations in percent by volume during static tests at probe and well locations at the Oxon Cove landfill. The methane concentration was fairly constant throughout the landfill area. Venting tests were conducted at two wells in the southern area of the landfill as indicated.

after longer term gas extraction from the landfill, the methane concentration will drop to 50 to 60% by volume.

At Oxon Cove (Fig. 4), the methane concentration was usually close to 60% in gas samples taken throughout the landfill area. The gas consisted almost entirely of methane and carbon dioxide, with small amounts of hydrogen usually present.

Pumping Tests at Kenilworth

After the initial static testing of gas samples from the installed wells, two wells at Kenilworth were selected for pumping tests (which involved extracting landfill gas with a mobile blower system) to study the effects that gas extraction would have on gas composition and to provide data on the quantity of gas available. At both wells, indicated on Fig. 3, gas was continuously withdrawn from the landfill for a period of two weeks.

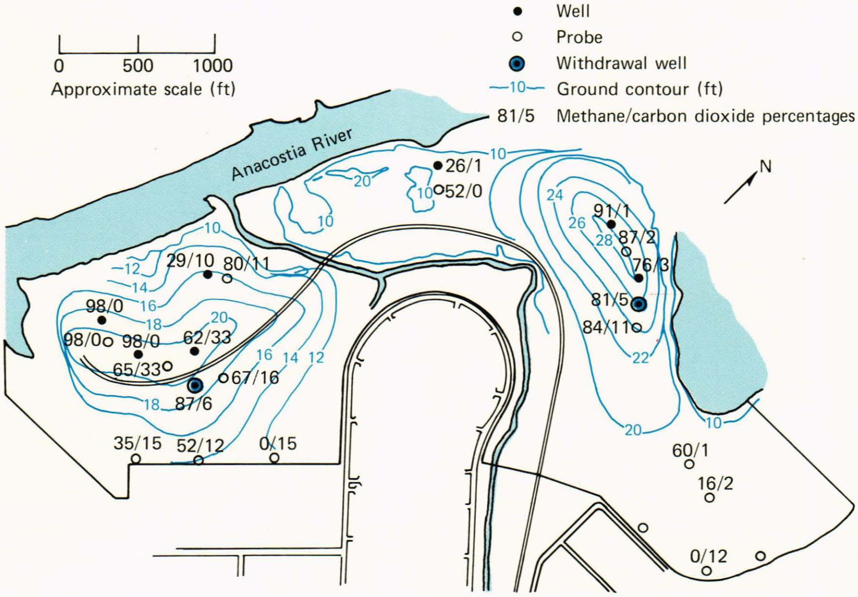

Fig. 3—Shown are the average methane and carbon dioxide concentrations in percent by volume during static tests at probe and well locations at the Kenilworth landfill. Two areas of the landfill had unusually high methane concentrations. Pumping tests were conducted at one location in the northern area and one in the southern area of the landfill at the wells indicated.

In addition, on one day at the northern withdrawal well and on two days at the southern well, a series of pulsing tests was completed during which the flow rates were increased for a short period of time. The blower was then shut off and the internal pressure of the landfill monitored at a nearby probe or well. The purpose of the pulsing tests was to get an idea of how large an area was affected by pumping at a certain rate. This is of importance in determining the spacing of recovery wells if a large-scale collection system is planned.

The average gas composition, temperature, and flow rate and the amount of gas withdrawn during pumping tests at Kenilworth are given in Table 1. During the two week pumping period at the northern withdrawal well at Kenilworth, the gas composition was fairly constant (Fig. 5). A nearby well and probe were monitored for gas composition and pressure. There was no significant effect on the gas composition at the locations due to the pumping. The pressure at both locations followed the barometric pressure as shown in Fig. 6. Turning the pump off at the withdrawal well revealed a small change in pressure at the probe and well being monitored; the pressure increased by 0.39 inch of water at the probe 93 feet away and by 0.34 inch of water at the well 113 feet away within an hour.

At the southern withdrawal well at Kenilworth, the gas composition also remained relatively constant throughout the pumping period. Gas composition and pressure at a probe 93 feet away were monitored while pumping at the second withdrawal well 113 feet away. The gas composition was not affected at the probe, and the pressure followed the barometric pressure as it did at the first pumping location. During pulsing tests, changes in pressure at the probe were relatively rapid; within half an hour of turning off the pump, the pressure increased by 0.16 inch of water.

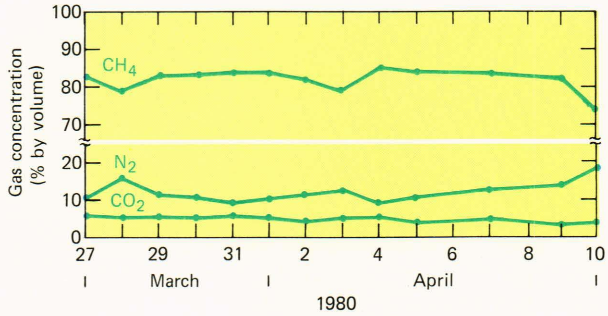

Fig. 5—During and after the two week pumping period at the northern withdrawal well at Kenilworth, the gas quality remained fairly constant.

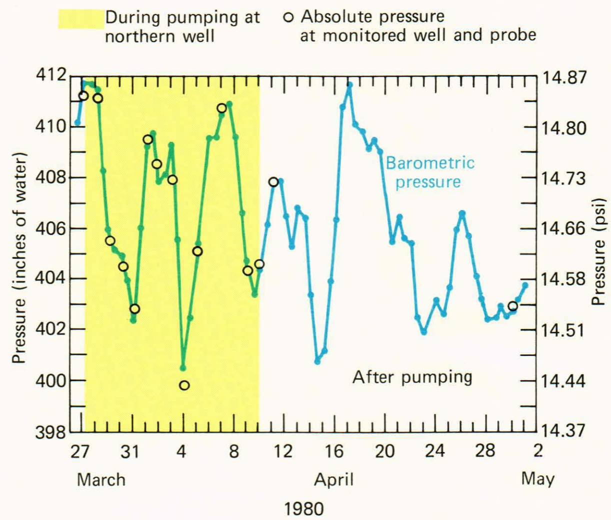

Fig. 6—During pumping tests at the northern well at Kenilworth, the landfill pressure was monitored at a well located 113 feet northwest and at a probe 93 feet southeast of the pumping location. The pressures at these two locations followed the barometric pressure closely.

Table 1

CHARACTERISTICS AND AMOUNT OF GAS WITHDRAWN DURING PUMPING TESTS AT TWO LOCATIONS AT THE KENILWORTH LANDFILL

	Northern Well	*Southern Well*
Average gas composition (%)	82 methane 13 nitrogen 5 carbon dioxide	92 methane 4 nitrogen 4 carbon dioxide
Average gas temperature (°F)	61	70
Gas flow rate:		
Average (ft^3/min)	44	62
Range (ft^3/min)	36 to 54	53 to 82
Amount of gas withdrawn (ft^3)	0.9×10^6	1.3×10^6

At Kenilworth, the relatively low gas temperature and internal landfill pressure might be a result of slow methane production. A slow gas production rate and infiltrating water carrying away dissolved carbon dioxide may explain the high methane concentration. The unusually high concentration might also be a result of the high ash content of the landfill stripping the carbon dioxide from the gas.

Venting Tests at Oxon Cove

Because the internal pressure of the Oxon Cove landfill ranged from 7 to 20 inches of water above atmospheric pressure, two wells were unplugged and allowed to vent naturally for a period of more than three weeks. The flow rates at both wells were initially high (greater than 100 cubic feet per minute) (ft^3/min), but dropped to a fairly steady 40 to 60 ft^3/min after two or three days. For over three weeks, composition of the venting gas at both wells remained nearly constant and internal landfill pressure remained consistently higher than barometric pressure. The average gas composition, temperature, and flow rate and amount of gas vented are given in Table 2. Venting did not affect the gas composition at nearby well and probe locations. Figure 7 illustrates the pressures recorded and the barometric pressures over the period of testing. Pressures appear to fluctuate with the barometric pressure but remain somewhat higher than barometric pressures over the entire period. The cause of the unusually high pressure is not fully understood but could result from the high percentage of moisture in the landfill enhancing gas production or the deep layer of cover material presenting a barrier to the rapid escape of generated gas.

Table 2

CHARACTERISTICS AND AMOUNT OF GAS WITHDRAWN DURING VENTING TESTS AT TWO LOCATIONS AT THE OXON COVE LANDFILL

	First Well	*Second Well*
Average gas composition (%)	62 methane 38 carbon dioxide	62 methane 38 carbon dioxide
Average gas temperature (°F)	58	61
Average gas flow rate (ft^3/min)	51	57
Amount of gas withdrawn (ft^3)	1.8×10^6	2×10^6

UTILIZATION OF THE LANDFILL GAS

Kenilworth

The planned end uses of the landfill gas at Kenilworth Park are space heating and electricity at the nearby Kenilworth greenhouses. These end uses require only minimal processing of the gas to remove particulates and moisture. Average annual natural gas consumption for the greenhouses for the years 1977, 1978, and 1979 was 2,858,700 ft^3. Monthly gas consumption ranged from a low in summer of 7900 ft^3 to a high in winter of 708,600 ft^3. During the same period, annual electricity consumption averaged 47,410 kilowatt-hours ranging from 2180 to 7400 kilowatt-hours per month.

The Aquatic Garden greenhouses located between the Kenilworth greenhouses and Kenilworth Park may also use the landfill gas. The Aquatic Garden greenhouses are assumed to have the same space heating and electricity requirements as the Kenilworth greenhouses.

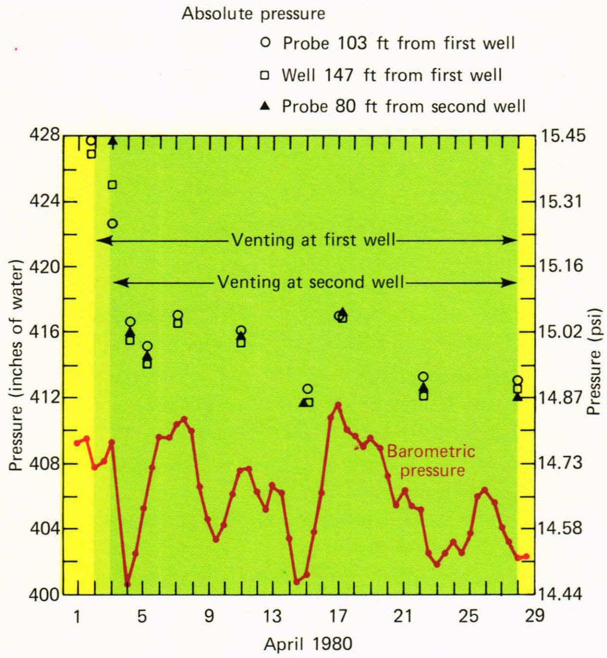

Fig. 7—During venting tests at the two wells at Oxon Cove, the landfill pressure was monitored at nearby well and probe locations. While venting at one location, pressures were monitored at a well 147 feet and at a probe 103 feet from the venting well. At the second venting location, pressures were monitored 80 feet from the well. Landfill pressures appear to fluctuate with the barometric pressure but remained higher than barometric pressure over the testing period.

The peak monthly requirements translate into a peak rate of gas demand of 16.4 ft^3/min of natural gas and 10.3 kilowatts of electricity. Since natural gas has twice the heating value of landfill gas, about 33 ft^3/min of landfill gas are needed to satisfy the peak monthly space heating needs at the Kenilworth greenhouses. Another 4.6 ft^3/min are needed to provide for the peak monthly rate of electricity supplied by an internal combustion engine-generator set with a conversion rate of 1 kilowatt-hour per 27 ft^3 of medium Btu landfill gas.[5] With a duty cycle of 50% during periods of peak consumption, peak instantaneous rates of landfill gas consumption of 66 ft^3/min and 9.2 ft^3/min result for space heating and electricity, respectively. Doubled to include the Aquatic Garden greenhouses, a peak instantaneous requirement of about 150 ft^3/min exists.

The gas well configuration (the number and location of wells) can be based upon the peak monthly requirements (75 ft^3/min); the processing, pumping, and transmission equipment sizing should be based upon the peak instantaneous requirement of 150 ft^3/min.

Oxon Cove

As stated previously, intended uses of the landfill gas at Oxon Cove are undetermined, although the most attractive use of the gas is to provide electricity generation and/or space heating for the buildings of the Oxon Hill Farm. Because this would require a relatively small quantity of the gas available, additional plans for utilization of the gas need to be developed.

CONCLUSIONS AND RECOMMENDATIONS

Kenilworth

The static and pumping tests at Kenilworth landfill indicated that enough methane gas is available to supply both the Kenilworth and Aquatic Garden greenhouses with the required amount of fuel for space heating and electricity generation. A recovery system could be designed to use the gas generated in the northern portion of the landfill.

The fairly stable level of methane concentration (75 to 85% by volume) at the northern withdrawal well at Kenilworth during the two weeks of pumping at flow rates ranging from 36 to 54 ft^3/min indicates the capacity of the well was not overloaded. Three such wells, with an average withdrawal rate of about 25 ft^3/min at each, could provide the total estimated maximum monthly rate of 75 ft^3/min of medium Btu landfill gas needed by the Kenilworth and Aquatic Garden greenhouses. This takes into account the fact that the heating value of the landfill gas might drop to a typical 500 Btu/ft^3 once pumping has continued for a long period of time. A collection system with five or six wells would not only yield enough landfill gas for both sets of greenhouses but would also provide flexibility so that if problems were encountered with a well, it could be removed from the system without total shutdown. Possible problems requiring a well to be removed from the system include the well being clogged with groundwater or decreased quality of the gas from the well because of air intrusion through the surface of the landfill.

The recovery wells should be spaced at approximately one per acre. The recovery well design may be similar to the test well design, and at least one of the test wells could be used as a recovery well. The recovery wells should be equipped with a valve at each wellhead so that the flow from each well can be controlled. The design should provide for access to each wellhead to allow for testing.

A preliminary economic analysis of a collection-processing-transmission system for Kenilworth has been performed.[6] The value of energy displaced, at mid-1980 prices, is about $37,000 per year assuming very conservatively that natural gas (for heating the Kenilworth greenhouses) costs $4.00 per million Btu, fuel oil (for heating the Aquatic Garden greenhouses) costs $1.00 per gallon, or $7.25 per million Btu, and electricity costs 5.0 cents per kilowatt-hour. The preliminary analysis of costs associated with a landfill methane recovery and utilization system indicated a total installed cost of $163,000 and a yearly operating and maintenance cost of $14,000. A simple payback period of about 7.1 years results.

It is expected that the entire northern section of the landfill would be needed for the greenhouses. Because the Kenilworth landfill is already over 10 years old, this northern area should supply enough gas for this purpose for 10 to 20 years. Due to the unusual nature of the gas composition and the uncertainties involved in predicting the life of the landfill gas, it is advisable to develop this one area and to continue testing. It may become necessary to use portions of the southern part of the landfill for the greenhouse application. However, if the landfill continues to generate gas at an acceptable rate and with a reasonable methane concentration, alternative uses for the gas in the southern area of the landfill (such as space heating for a nearby maintenance building) can be investigated.

Oxon Cove

At Oxon Cove, static and venting tests indicate that there is a significant quantity of medium Btu landfill gas available at a relatively high pressure. It would be straightforward to provide the required energy for the Oxon Hill Farm because it is only a fraction of the estimated gas resource at Oxon Cove. Further end uses of the gas, including generation of electricity for sale to the local utility, need to be explored in some detail. An estimated minimum of 300 ft^3/min of gas is available (150 ft^3/min from the southern part of the landfill and 150 ft^3/min from the northern part).

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