J. ENVIRONMENTAL SYSTEMS, Vol. 16(2), 1986-87

THE EFFECT OF INCREASING LANDFILL SIZE ON THE ECONOMIC VIABILITY OF LANDFILL GAS RECOVERY

KEVIN CROKE, PH.D.
University of Illinois at Chicago
Chicago, Illinois

R. ERIC ZIMMERMAN, PH.D.
ESCOR, Inc.
Northfield, Illinois

ABSTRACT

Landfill gas utilization has seen continual growth since 1975. Two principal reasons are the growing competitiveness of gas as a commercial and industrial fuel, and more stringent environmental regulations. Pressures from citizens and regulators have combined to decrease the number of landfills, and new landfills will generally be larger facilities that serve area-wide jurisdictions such as whole counties. As sanitary landfills, the source of landfill gas (LFG), increase in size LFG recovery is expected to become more economical. This article examines the impact of the expected landfill size increase over the next decade on the economics of LFG recovery. The percentage of landfill capacity expected to yield an adequate internal rate of return in 1995 is discussed, given the present and expected size distributions of landfills in the United States. The source and recovery of LFG, and models employed to estimate internal rates of return for LFG projects are discussed. LFG revenues and expenses are projected, based on production feasibility models developed by the U. S. Department of Energy and the Gas Research Institute.

LANDFILL GAS PRODUCTION

Landfill gas generation is a natural process that occurs through the bacterial decomposition of organic matter in a landfill. This process proceeds through stages that are controlled by local site conditions, e.g., pH, temperature, moisture, and oxygen content (both gaseous and chemically available) that

doi: 10.2190/YFXN-YJ7X-PNC9-24DK
http://baywood.com

affect the bacterial population. In an active landfill, refuse is placed daily in individual "cells" that are then covered with soil. The gas generated from the entire landfill reflects the sum of the decomposition occurring in the individual cells. Within an individual cell, methane is produced after the conditions in the voids change from aerobic to anaerobic and the chemically available oxygen in the refuse is consumed. The type of organisms, rates of reaction, and completeness of the reaction are controlled by the availability of oxygen and the temperature range in which the process takes place.

Figure 1 shows the relative concentrations of gases in a landfill as decomposition proceeds from aerobic to anaerobic. The aerobic Phase-I decomposition lasts from several days to several months and carbon dioxide is produced. In Phase-II, oxygen is depleted and hydrogen and carbon dioxide increase. Methane production begins in Phase-III after the oxygen (both gaseous and chemically available) is consumed. In Phase IV, gas production approaches a steady-state condition. After Phase-IV, the gas is approximately 50 to 60 percent methane and 40 to 50 percent carbon dioxide, depending on landfill volume, availability of moisture and nutrients, refuse composition, and other site conditions.

ESTIMATING LANDFILL GAS PRODUCTION

Daily or annual LFG production are estimated from the existing and potential tonnages of waste in place. The quantity of gas generated from a given quantity of waste during a given time period is not precisely known. However, published rates based on observation of past recovery projects vary from 80 to 280 scf LFG/ton waste [2]. These relationships are:

(1) Low case: tons in place x 80 scf LFG/ton = annual production
High case: tons in place x 280 scf LFG/ton = annual production.

In the analysis presented here, 80 scf/ton is assumed in estimating annual production.

ESTIMATING COST AND REVENUES

The three LFG utilization options considered here are:

1. producing medium-Btu gas which requires minimal capital and operating and maintenance (O&M) costs due to the minimum requirements of the gas cleanup;
2. producing high-Btu gas on the same basis, with related capital and O&M cost above those of the medium-Btu gas; and
3. producing gas for electrical generation, which requires the highest capital costs, but typically yields the highest gross revenues.

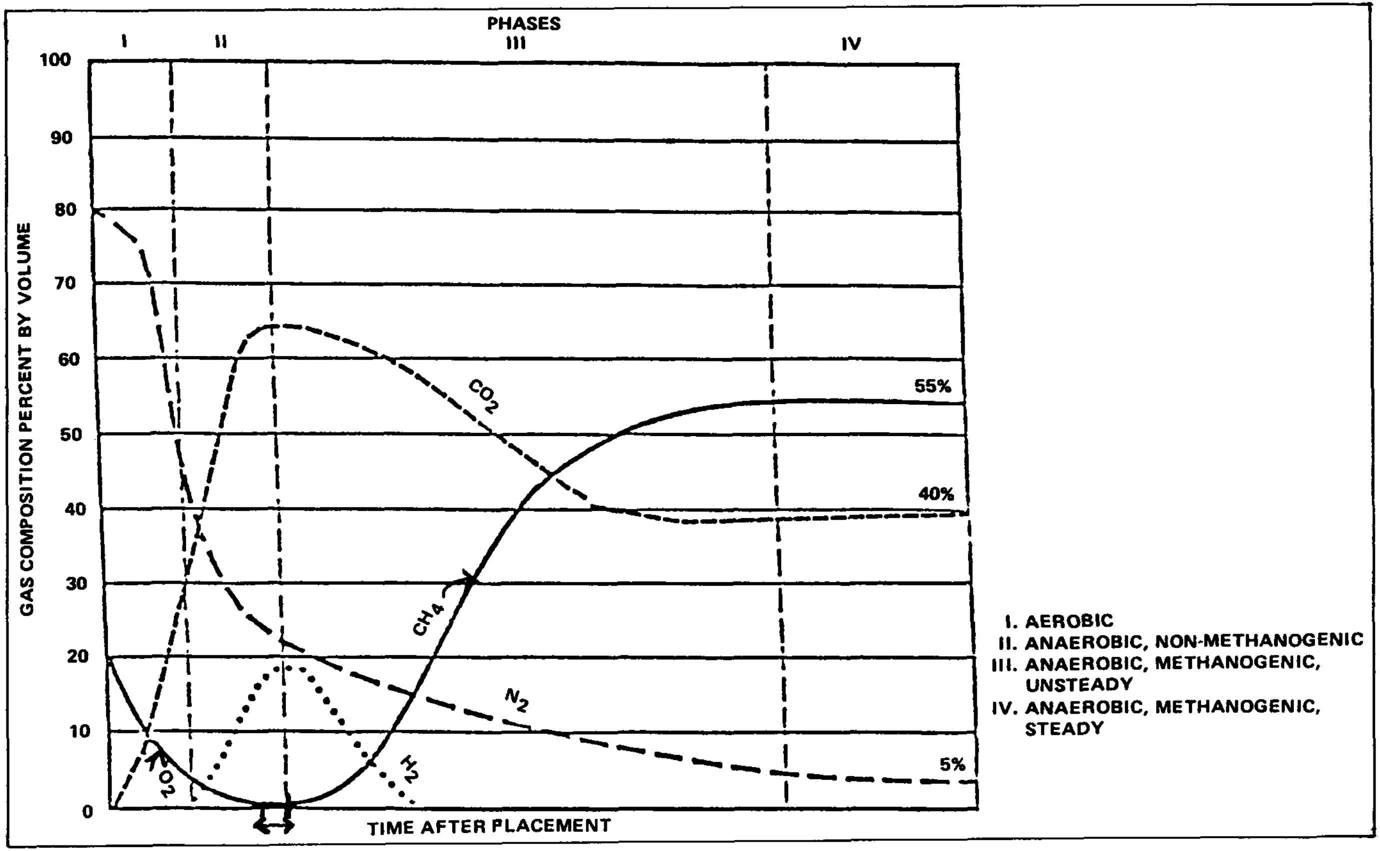


Figure 1. Gas composition and evolution in a typical landfill [1].

The techniques employed here for estimating the capital and operating costs and projected revenues for these options are based upon Wilkey et al [3] and Zimmerman et al. [4]. The evaluation of the revenue and expenses of these options employs three basic equations to develop net revenue projections:

(2) Capital cost = A x annual production + B x 10.
(3) O&M costs = C x capital cost
(4) Gross revenue = annual production x 500 Btu/scf x E x sales price:
where A, B, and C are capital and operating cost coefficients based upon the utilization option selected, E is the "energy efficient factor," which is the amount of energy delivered to the user divided by the total amount of energy collected.

The O&M coefficient, C, is assumed to be 10 percent for all options [5]. For this study, a projected life of ten years was assumed, based upon a study by C-E Lummus [6]. Estimates for A, B, and E for the three utilization options are presented in Table 1, based upon Snyder [7], Weiss [8], and Wilkey et al. [3]. Zimmerman et al., in a review of these coefficients, indicated the only major change in these values since 1982 is sales price [4]. The reasons for the lack of cost increase are that the increases in labor and materials costs have been offset by improvements in technology and increased engineering knowledge of LFG recovery.

In 1981-82, gas utilities in the United States were paying $4 or more per million Btu of new gas. In 1985, the price was $2.50 to $3.00 per million Btu, and in 1986 it is $1.90 to $2.50 per million Btu. Thus, while the cost of collecting and producing high-Btu gas from LFG has remained essentially the same, the potential sales price has decreased. For this study, the 1985 prices of medium-Btu gas and high-Btu gas were assumed. Electrical power generated from the combination of recovered gas was priced at 6c/kwh [4].

Table 1. Cost Equation Coefficients and Energy Sales Price for 1982

	Capital		*Efficiency Factor*	*Estimated Sales Price 1982*
Utilization Option	*A*	*B*	*E*	*($/MMBtu)*
Medium-Btu Use	0.2	1.2	0.85	4.00
Electrical Generation	1.0	1.0	0.85	4.40
High-Btu Use	0.7	1.0	0.90	4.00

Equations 1 through 4 and the coefficients presented above were employed in a computer simulation to estimate internal rates of return of alternative gas recovery systems given that the tons in place of the landfill were known. The internal rate of return is that discount rate which yields a present value of the net revenues of a project equal to 0. The desirability of alternative LFG utilization options for different sizes of landfill was ranked according to their internal rates of return.

CHANGE IN SIZE DISTRIBUTION OF LANDFILLS

In order to use this model to estimate the change in rates of return over the next decade due to the trend toward larger landfills, information on the size distribution of landfills, classified by number of tons in place, was developed.

The sizes and locations of all active and inactive municipal landfills existing in 1984 and projected for 1995 were developed from previous data bases [5]. Table 2 shows that in 1984 there were more than 19,000 active and inactive municipal landfills in the United States [4]. This number is expected to increase by 21 percent to nearly 23,000 by 1995. A percentage breakdown based on tonnage in place at landfills is shown.

While the total number of landfills will increase over the next ten years, the number in the smallest category of landfills (those containing less than 500,000 tons) is expected to decrease. Many of the smallest-category active landfills are expected to increase their tonnages by 1995. As a result, the total number of landfills in this category is expected to decrease by 29 percent by 1995.

The other four size categories are expected to increase in number by 284 percent. Landfills in the next two size categories will grow in number by some

Table 2. Distribution of Landfills by Tonnage in Place 1984 and 1995

	1984		*1995*	
Tons in Place (10)	*Number*	*Percent of Total*	*Number*	*Percent of Total*
< 0.5	15,988	82	11,294	50
0.5 - 1.0	1,656	9	6,367	27
1.0 - 2.0	1,137	6	3,325	15
2.0 - 2.5	393	2	1,279	6
> 2.5	90	1	368	2

Note: 1 ton = 1016 kg.

200 percent each. Landfills in the category of more than 2.5 million tons will increase by 309 percent, rising from their 1984 level of 90 to 368 in 1995.

ESTIMATION OF INTERNAL RATE OF RETURN BY LANDFILL SIZE

Table 3 shows the internal rates of return of projects utilizing landfills of different sizes. Calculations were made using equations 1 through 4, and the landfill size categories defined in Table 2. Constant natural gas prices and costs were assumed over the ten year forecasting period. The sharp rise in rate of return with size is evident.

The internal rate of return estimates in Table 3 were employed with the Table 2 data on the landfill size distribution in 1984 and 1995 to forecast the shift in LFG market share over this period. The purpose of the analysis was to estimate the percentage of landfill capacity for which LFG projects would return at least a specified rate of return. The results are shown in Figures 2, 3, and 4. Examination of Figure 2 shows that over a wide range of required rates of return, the percentage of landfills in which the production of medium-Btu gas is desirable will rise by 20 percent over the next decade. For example, for a required rate of return of 25 percent, 45 percent of the landfill market could utilize medium-Btu gas recovery in 1985 while 65 percent of the market could employ LFG recovery in 1995.

For an equivalent 25 percent required rate of return, utilizing the electrical generation option, a market potential of 55 percent is estimated in 1985, while a market potential of 70 percent is forecast for 1995. At a 25 percent internal rate of return, high-Btu LFG projects perform about the same as low-Btu projects.

It should be emphasized that it is not the absolute market share projections which are the focus of this analysis. Much more of the LFG market could be

Table 3. Landfill Size vs. Internal Rate of Return

	Internal Rate of Return (Percent)		
Size of Landfill (Millions of Tons in Place)	*Electrical Generation*	*High-Btu Gas*	*Medium-Btu Gas*
< 0.5	0	0	0
0.5 - 1.0	15	12	6
1.0 - 2.0	30	26	25
2.0 - 2.5	38	35	41
> 2.5	45	43	62

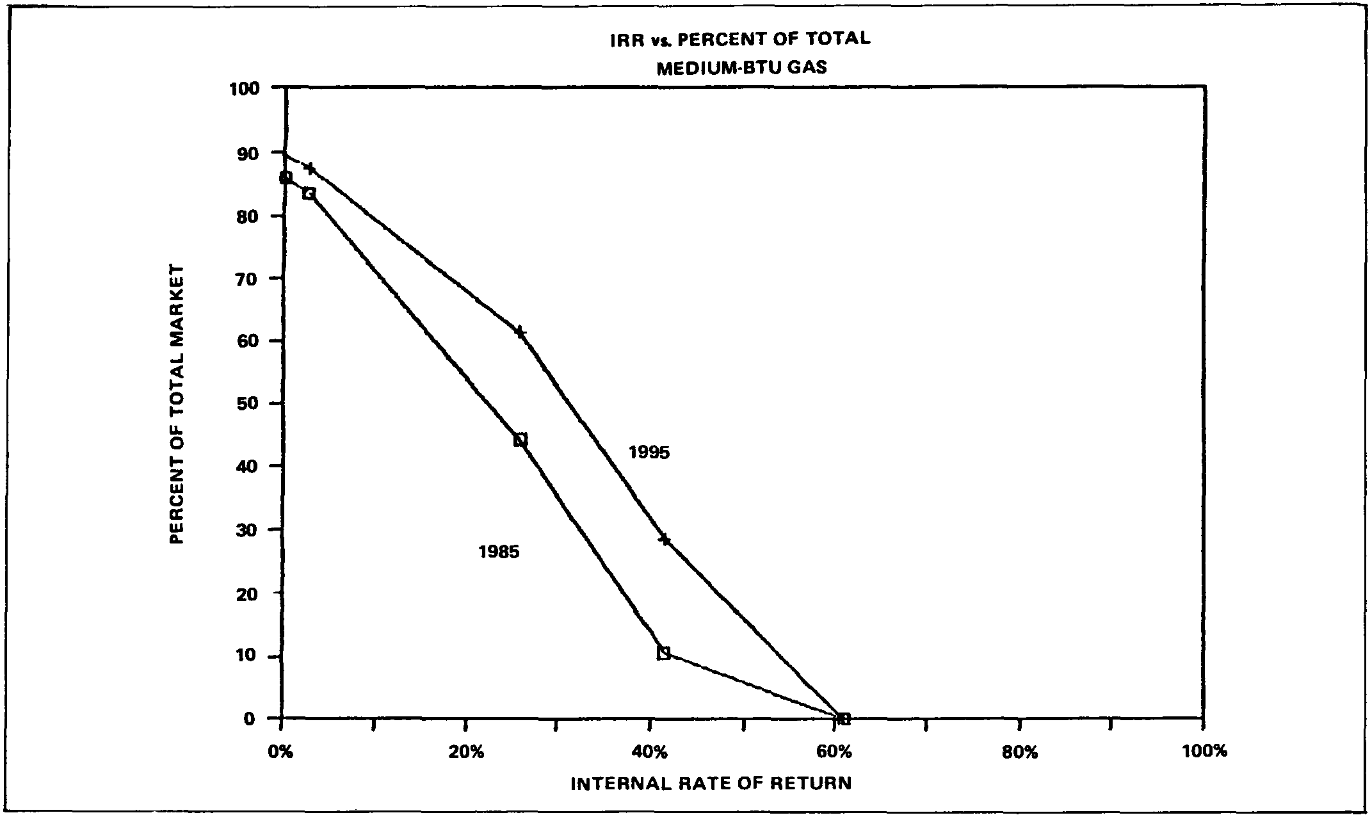
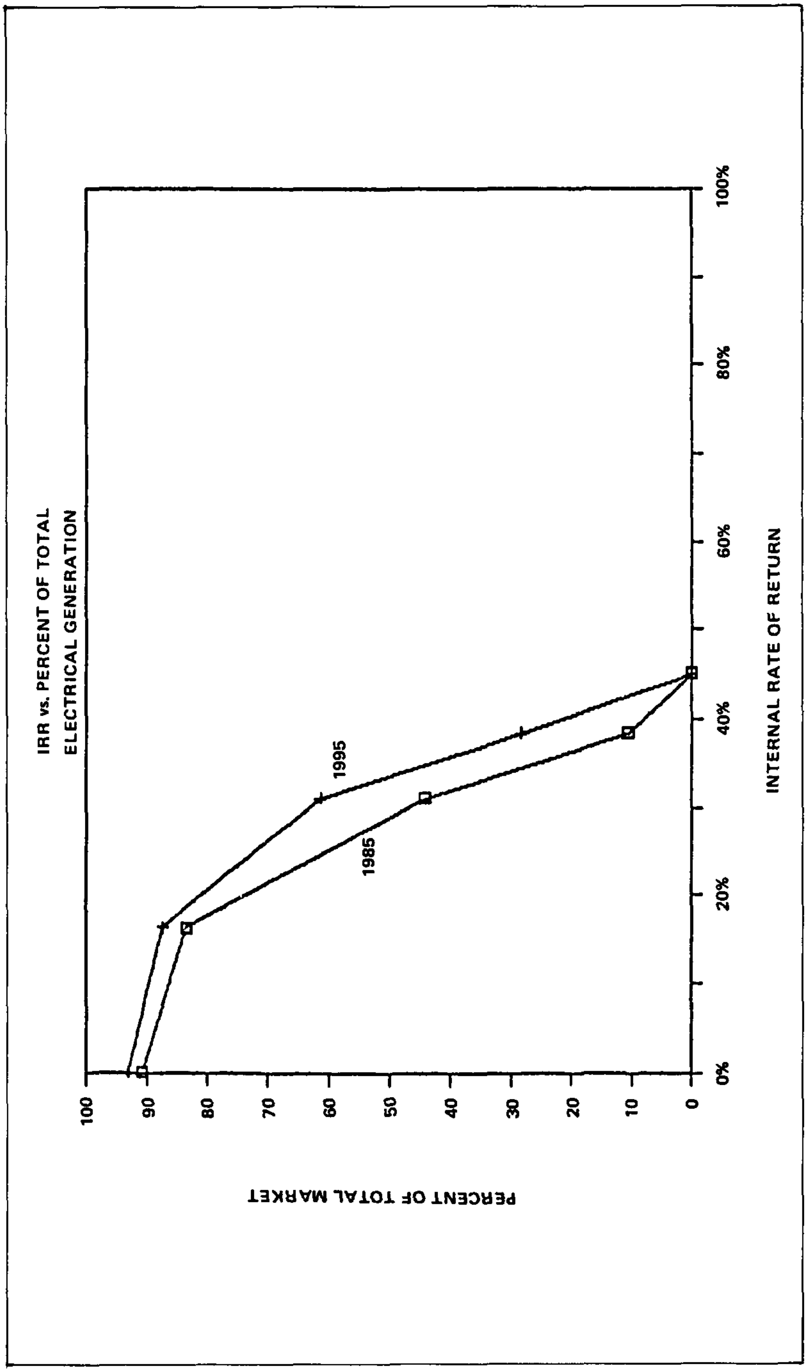


Figure 2. IRR vs. percent of total.



IRR vs. PERCENT OF TOTAL
ELECTRICAL GENERATION
1995
1985
PERCENT OF TOTAL MARKET
100
90
80
70
60
50
40
30
20
10
0
0%
20%
40%
60%
80%
100%
INTERNAL RATE OF RETURN

Figure 3.

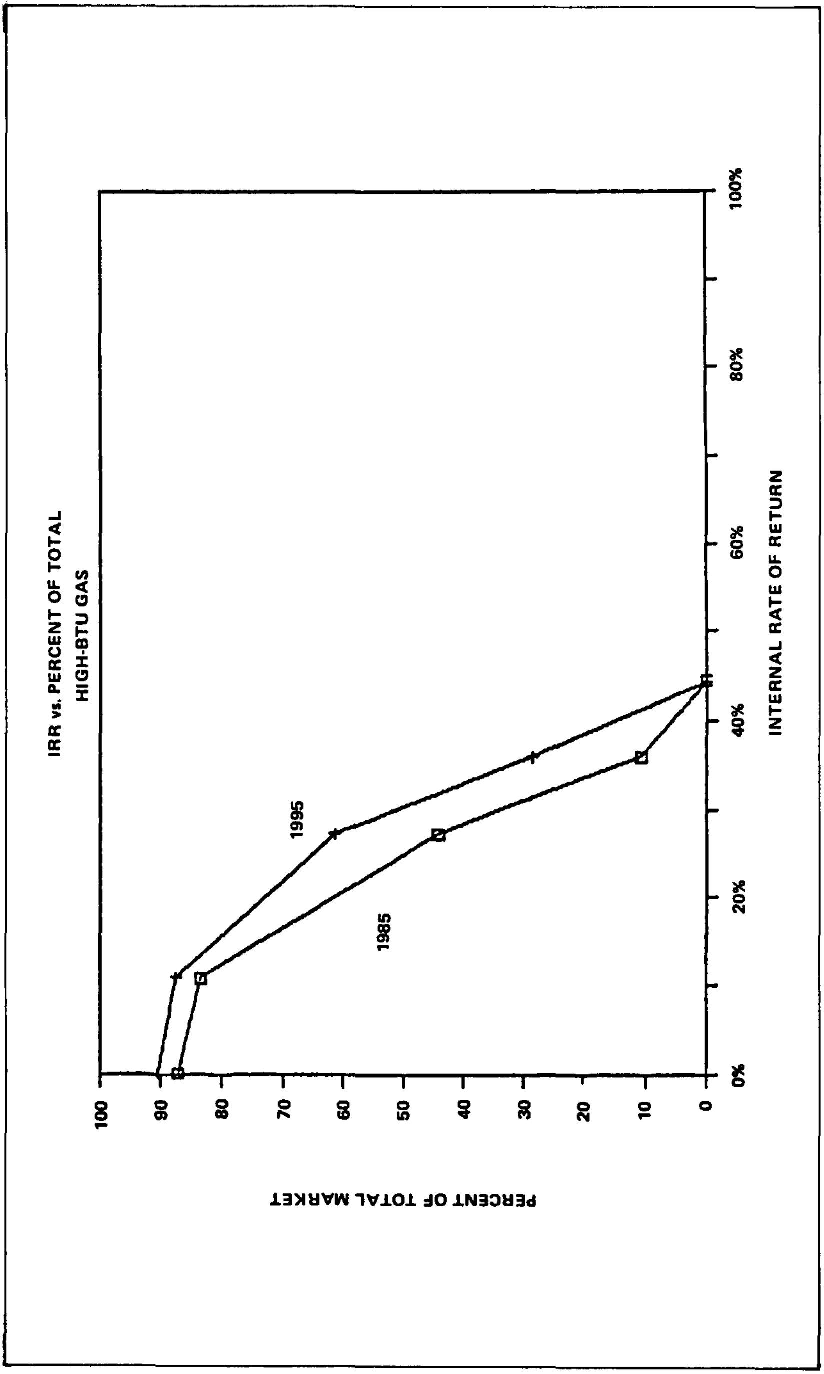

IRR vs. PERCENT OF TOTAL
HIGH-BTU GAS
PERCENT OF TOTAL MARKET
100
90
80
70
60
50
40
30
20
10
0
0%
20%
40%
60%
80%
100%
INTERNAL RATE OF RETURN
1995
1985

Figure 4.

profitably exploited now than is currently being developed. Many factors contribute to the present underutilization of LFG opportunities, including possible anticipation of further energy price decreases, lack of motivation by municipalities to get into the business of selling LFG, and a reluctance by gas and electrical utilities to depend on LFG supply. However, the shift in potential market share over the next decade as a result of increasing landfill size, as reported in Figures 2, 3, and 4, create the kind of market pressures which may overcome such impediments to LFG development in the next decade.

CONCLUSIONS

In the late 1970s and early 1980s, the rapid rise of energy prices generated considerable interest in LFG recovery. The recent decreases in energy prices has, however, dampened enthusiasm for investing in LFG projects. Given the trend in the distribution of landfill size and the sensitivity of internal rate of return with size, even if the estimates presented here of market share in 1985 and 1995 are optimistic, this analysis would seem to indicate conditions for a strong resurgence of interest in LFG recovery and an expanding market share for recovery technologies.

In fact, the estimates of the increase in market share from 1985 to 1995 are probably conservative for a number of reasons:

1. The technology of LFG recovery has shown considerable improvement over the last few years. The improvement should continue to hold cost of LFG recovery down.
2. Over the next decade, the price of natural gas may again start to increase as the present energy supply surplus disappears.
3. Future regulation of landfills may well dictate the collection of LFG for reasons of safety and environmental protection. The incremental cost of commercially marketing the gas over and above the cost of simply collecting and flaring it would then become the appropriate cost estimate in a rate of return analysis. This adjustment would considerably improve the attractiveness of LFG recovery projects.

REFERENCES

1. G. H. Farquhar and F. A. Rovers, Gas Production During Refuse Decomposition, *Water, Air and Soil Pollution, 2*:10, 1973.
2. EMCON Associates, *Methane Generation and Recovery from Landfills*, AnnArbor Science Publishers, Ann Arbor, MI, 1980.
3. M. L. Wilkey, R. E. Zimmerman, and H. R. Isaacson, *Methane From Landfills: Preliminary Assessment Workbook*, Argonne National Laboratory, Report No. ANL/CNSV-31, 1982.

4. R. E. Zimmerman, J. J. Walsh, and M. L. Wilkey, *Landfill Gas: Resource Evaluation and Development*, ESCOR, Inc., Gas Research Institute, Contract No. 5084-224-0989, 1985.
5. SCS Engineers, *Case Study: City of Industry Landfill Gas Recovery Operation*, Argonne National Laboratory, Report No. ANL/CNSV-TM-91, 1981b.
6. C-E Lummus, *Landfill Gas Recovery Project Study*, City of San Antonio, October 1983.
7. N. W. Snyder, *Biogas Treatment to High-Btu Gas Technical and Financial Analysis*, Proceedings from the GRCDA 7th International Landfill Gas Symposium, Piscataway, NJ, April 1984.
8. I. Weiss, *The Economics of Landfill Gas Recovery*, Proceedings from the GRCDA 7th International Landfill Gas Symposium, Piscataway, NJ, April 1984.

Direct reprint requests to:

Kevin Croke, Ph.D.
Associate Professor
School of Public Health
University of Illinois at Chicago
Chicago, IL 60680