

A RESOURCE PLANNER'S ENVIRONMENTAL HANDBOOK FOR LANDFILL
GAS-TO-ELECTRICITY GENERATION PROJECTS: A STUDY OF THE
EMERALD PEOPLE'S UTILITY DISTRICT'S SHORT MOUNTAIN
LANDFILL METHANE-TO-ELECTRICITY GENERATION
PROJECT

by

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A THESIS

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Landfill gas is a renewable resource that can be used as a substitute fuel for natural gas. Methane produced from the anaerobic decomposition of biodegradable solid waste in landfills may be used to fuel electricity generation facilities. Across the United States, this source of energy remains largely untapped. Landfill gas emissions are hazardous to the public's health and welfare and are a source of environmental degradation, when not controlled. Landfill gas recovery-to-electricity projects control the emission of landfill gas to the atmosphere and provide a source of fuel for electrical power generation.

These projects do present environmental problems that must be studied in an analysis of the environmental costs and benefits of this energy source. The Emerald People's Utility District's Short Mountain Landfill Methane-to-Electricity Project is the subject of this planning study of the environmental costs and benefits of using landfill gas as a fuel source for electricity generation.

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DEDICATION

To Mom and Dad

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CHAPTER I

INTRODUCTION

Landfill gas (LFG) is a renewable resource that can be recovered for use as a commercial substitute fuel for natural gas. Landfill gas is produced from the anaerobic decomposition of biodegradable municipal solid waste (MSW) in landfills. Landfills contain a large amount of biodegradable solid waste covered with a cap of compacted dirt to control odor and vermin at the site. Landfill gas is created in the restricted oxygen (O_2) environment of sanitary landfills that promotes the growth of a type of bacteria called methanogens. Methanogens generate methane and carbon dioxide as byproducts of their life-cycle. The LFG consists of approximately equal parts of methane (CH_4) and carbon dioxide (CO_2), with less than one percent composed of other trace gases.

There are two major reasons why landfill gas is so important. First, landfill gas can be a troublesome source of safety and environmental problems if it is not properly regulated and controlled. Second, landfill gas has significant potential for use as a fuel if it is recovered.

Pressures build within the landfill as landfill gas is generated. Eventually, this pressure will either force the gas into the atmosphere or to migrate laterally underground. When the LFG migrates underground, it can escape the landfill at its boundaries. Methane in the landfill gas can accumulate in basements and other subsurface structures near the landfill or in low lying areas around the landfill. Methane gas in concentrations greater than five percent is extremely combustible. "In concentrations between five and fifteen percent by volume in

air, methane is flammable at atmospheric pressure and ordinary temperatures."¹ The ease with which methane can migrate through soil heightens the potential hazard. Property damage and/or injuries to people and even death can result from this volatile concentration of methane if explosions do occur.

Additionally, migrating landfill gas may cause damage or kill vegetation at or near the landfill, depending on the vegetation's sensitivity to carbon dioxide and methane, oxygen depletion and elevated soil temperature.² Methane and carbon dioxide displace oxygen in the soil as they migrate through, as well as elevating soil temperature.

Landfill gas may escape the landfill surface cover and carry contaminants into the atmosphere. Methane and carbon dioxide, the two major component gases of landfill gas, are proven "greenhouse gases" that contribute to the phenomena of global warming. Trace gases in the LFG can themselves contribute to air pollution or eventually react in sunlight to form smog. Hydrogen sulfide gas (H_2S), one of the trace gases formed by the decay or decomposition of solid waste, carries with it the offensive "rotten egg" odor that people associate with landfills and can be hazardous to human health in atmospheric concentrations over 50 ppm (parts per million). Volatile organic gases of decomposition also contribute to the nuisance of malodors.

Landfill gas is a medium-Btu gas, approximately 500 Btu/ft³ (British thermal unit per cubic foot), that can be used as a fuel for industrial steam boilers at or near the landfill site or for on-site generation of electricity. The recovered

¹EMCON Associates and Gas Recovery Systems, Inc., Landfill Gas: An Analysis of Options, San Jose, California, May 1981, p. 3.

²Ibid., p. 4.

landfill gas need only be filtered, dehydrated, and then compressed for use as a fuel. Processing of landfill gas to remove the carbon dioxide component gas produces a high-Btu fuel (900 - 1000 Btu/ft³), suitable for use as a pipeline-quality natural gas substitute.

Most urban areas now have large operating landfills from which landfill gas recovery is feasible, based on the volume of refuse in place. Rural areas and smaller cities rely almost exclusively on sanitary landfills for disposal of solid waste. According to GRCDA - The Association of Solid Waste Professionals, figures taken from EPA's Agenda for Action show that 160 million tons of new solid waste are generated annually in the United States. Eighty percent of this new solid waste is deposited in landfills across the United States each year, rapidly increasing the landfill gas resource base. Solid waste decomposition produces, on average, approximately 0.1 scf/lb per year (standard cubic foot per pound per year). The quality and amount of gas produced is dependent on solid waste content, landfill moisture levels, compactness of the waste, age of the substrate, and the anaerobic condition of the landfill. A calculated yield of 26 billion cubic feet of landfill gas (GRCDA figures) is produced annually from landfills in the United States.³ Industry professionals assume that landfill gas collection systems can only recover 40 - 90% of the gas generated in a landfill, so this figure may overstate the actual annual recoverable landfill gas reserves.⁴

Until the early 1970's, the natural production of landfill gas was viewed as an undesirable, but inevitable byproduct of placing solid urban waste in sanitary

³Stephen Hirshfield, Programs Engineer, "Personal communication," GRCDA - The Solid Waste Management Professionals, Silver Spring, Maryland, May 18, 1990, p. 1.

⁴Ibid., p. 1.

landfills. The desire to mitigate the negative environmental impacts of landfills and price rises in fossil fuel markets of the 1970's created interest in the recovery and uses of landfill gas.⁵

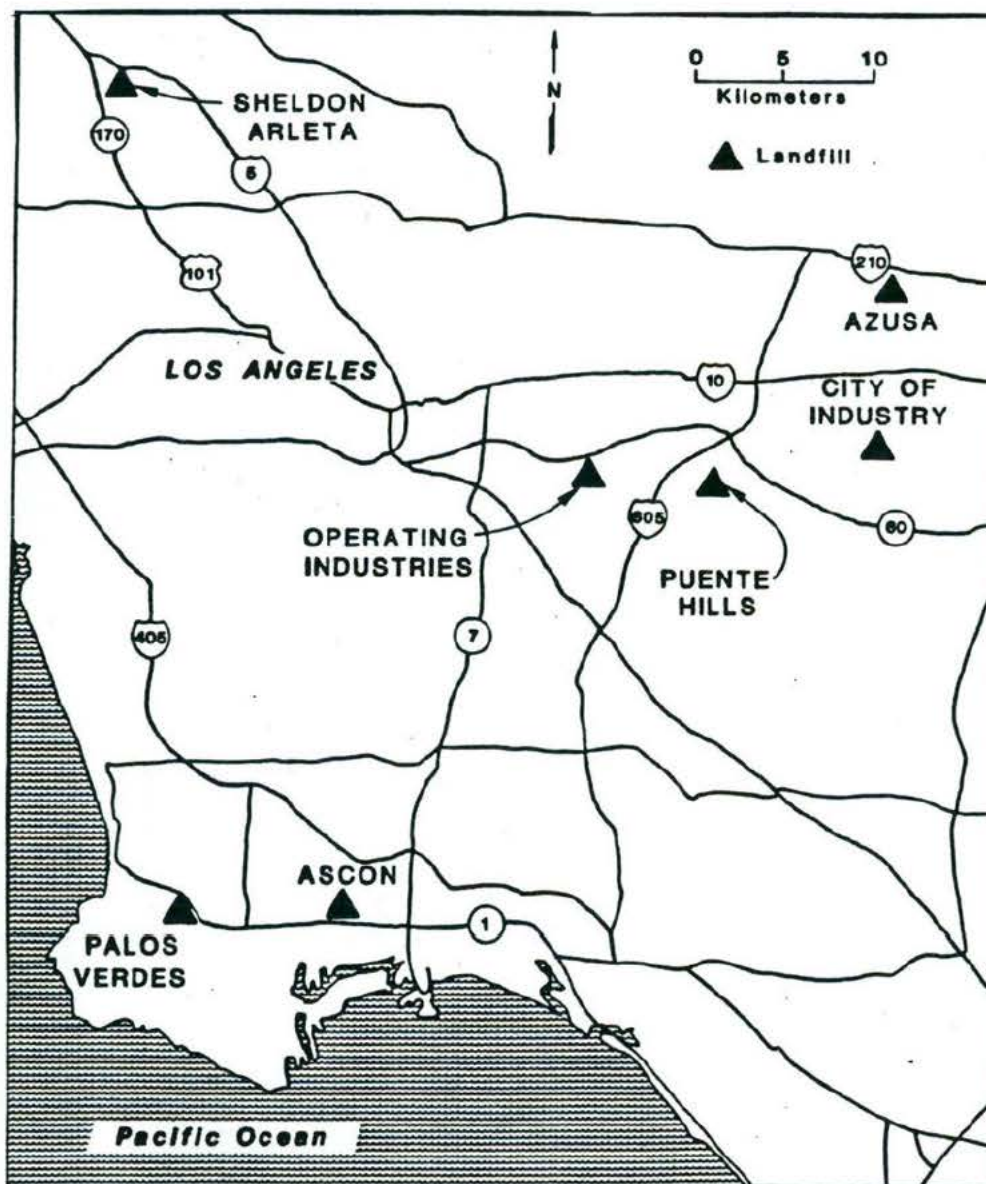
The first methane recovery for commercial use project in the United States was constructed south of Los Angeles in 1975, at the Palos Verde Landfill, Rolling Hills Estates, California. Processed gas from the project is sold to Southern California Gas Company and blended into natural gas pipelines. The first project to use landfill gas to fuel electricity generators was completed in November 1979 at the Sheldon -Arletta Landfill, Los Angeles, California. Processed LFG is transported 2.4 kilometers to the Valley Steam electrical generating plant for use as a boiler fuel and supplemental fuel. Earlier, during 1974 and 1975, the Department of Water and Power for the City of Los Angeles and the Los Angeles Department of Sanitation had demonstrated at the Sheldon - Arletta Landfill that unprocessed landfill gas could be used to fuel an internal combustion engine attached to an electrical generator.⁶ Figure 1 shows the locations of the Palos Verde and the Sheldon - Arletta Landfills.

In 1976, the United States Environmental Protection Agency (EPA) set regulatory guidelines for landfill gas migration at all operating landfills in the United States. These regulations were promulgated under the Resource Conservation and Recovery Act of 1976 (RCRA) amendments to the Solid Waste Disposal Act of 1965 (SWDA). Currently, requirements established by the EPA under RCRA state that methane concentrations from landfills cannot exceed 1.25

⁵James R. LaFevers, Robert L. Beck, Karen L. Harrington, Gary M. Kaszynski, and Fran Kremer, The Environmental Impacts, Institutional Problems, and Research Needs of Sanitary Landfill Methane Recovery, Argonne National Laboratory, Argonne, IL, ANL/CNSV-TM-86, 1981, p. 1.

⁶EMCON Associates and Gas Recovery Systems, Inc., Landfill Gas: An Analysis of Options, San Jose, California, May 1981, p. 47.

FIGURE 1: Original Landfill Gas Recovery Projects



Source: Argonne National Laboratories, The Environmental Impacts, Institutional Problems, and Research Needs of Landfill Methane Recovery, ANL/CNSV-TM-86, June 1981, p. 44

percent in an enclosed structure or a lower explosive limit of 5 percent (10 percent LFG) at landfill boundaries. These criteria make gas control or collection systems mandatory at many sanitary landfills.⁷ Increasingly restrictive regulation of landfill operations and more extensive environmental monitoring is being implemented by federal, state, and local governmental agencies. The EPA is in the process of promulgating new regulations for landfills receiving municipal solid waste. Stricter requirements limiting gaseous emissions and increased levels of soil gas monitoring will be a part of the new regulations. Stringent environmental regulations, low natural gas market prices, and a loss of a portion of alternative energy tax credits have slowed development of landfill gas as an alternative energy resource.

The tough new Environmental Protection Agency regulations may once again spur development of landfill gas recovery projects as landfill operators seek to comply with the more stringent limits on gaseous emissions. Landfill gas recovery projects thus may be viewed as a part of environmental compliance. On-site use of the recovered gas for electricity generation or as a boiler fuel can be used by landfill operators as means of offsetting the cost of compliance with environmental regulation. Commercial sale of processed landfill gas to a pipeline or excess electric power to the grid may not only cover the cost of environmental compliance, but also provide real income to the landfill operator.

It is necessary, of course, to identify and balance the negative impacts of landfill gas recovery and use against the benefits to be gained by eliminating some of the adverse environmental impacts caused by landfills. The benefits to be gained are summarized by the Argonne National Laboratory as follows:

⁷Ibid., p. 8.

- Prevention of methane migration and accumulation in concentrations great enough to cause explosions or fires.
- Prevention of asphyxiation of vegetation by displacement of oxygen by methane and carbon dioxide.
- Reduction of odor emanating from the landfill.
- Reduction of hydrocarbons and other pollutants escaping to the atmosphere.
- Enhancement of animal life on reclaimed sites.⁸

Landfill gas recovery projects entail a number of adverse impacts, both real and perceived. Again, the Argonne National Laboratory summarizes the potential adverse impacts as follows:

- Odor from wells and from material removed from wells.
- Odor from some collection systems and from the processing facilities, especially during down time.
- NO_x emissions from compressors, engines, and other equipment.
- Excessive CO₂ emissions.
- Hydrocarbon emissions.
- Noise caused by compressors, other processing equipment, construction, etc.
- Light from flares, regarded as a nuisance in some locations.
- Leachate problems that may develop in response to enhancement practices.
- Condensates, which may be hazardous and/or which could cause disposal problems.
- Air quality impacts that may result from burning LFG with variable and unknown trace constituents.⁹

All these environmental costs and benefits must be weighed and the tradeoffs and possible net benefits considered when project planning enters the decision-making processes.

⁸James R. LaFavers, and others, The Environmental Impacts, Institutional Problems, and Research Needs of Sanitary Landfill Methane Recovery, Argonne National Laboratory, Argonne, Illinois, ANL/CNSV-TM-86, June 1981, p. 2.

⁹Ibid., pp. 4-5.

Thesis Purpose, Research, and Methodology

The Emerald People's Utility District (EPUD or Emerald PUD) of Eugene, Oregon is in the process of developing a landfill methane recovery-to-electricity project at Lane County, Oregon's Short Mountain Landfill. Preliminary work on the project is complete and the Emerald PUD is now awaiting the completion of final design changes before proceeding with the project. When the project's construction is complete, the methane extracted from the Short Mountain Landfill will be burned in on-site internal combustion engines to generate electricity for the utility's customers.

This thesis contains a study of the environmental problems caused by landfill gas generation, the planning and siting of landfill gas recovery to electricity projects and the environmental benefits and costs of using landfill gas as a resource fuel for electricity generation. Finally, the study concludes with a brief discussion of the potential for landfill gas-to-electricity projects in the State of Oregon based on data supplied by the staff of the Oregon Department of Energy. The Emerald People's Utility District's Short Mountain project will serve as a case study of the benefits to be gained by landfill gas recovery and the environmental concerns that resource planners must address in developing landfill gas recovery-to-electricity generation projects.

The research material on landfill gas, landfill gas recovery systems, and the use of methane as a fuel for electricity generation came from a broad spectrum of government agency documents and regulations, the publications of private consulting firms, and personal communications with solid waste and energy organizations expert in the field of waste to energy generation projects. I served as a student intern in resource planning at the Emerald People's Utility

District from January through March of 1990, specifically to help in the planning and development of the Short Mountain Project. While there, I assisted in writing the application for the air contaminant discharge permit required of the Short Mountain Landfill Methane-to-Electricity Project. Upon completion of the application process, I helped to complete the final equipment and project bid documents for the Short Mountain Project. Much of the data used in the case study of the Short Mountain Project was gathered during the internship. Alan Zelenka, resource specialist at the Emerald People's Utility District, supplied the remainder of the information used in the case study from his personal files.

Academic tradition holds that a thesis must ask and answer a specific research question. The format of this thesis breaks with tradition and does not attempt to answer a specific research question for which there is no single correct answer. The methodology employed in the research and writing of this thesis is intended to incorporate information of an interdisciplinary nature into a comprehensive study of the environmental costs and benefits of generating electricity with methane recovered from solid waste landfills. This thesis is meant to be a practical resource planning document that distills information from across the boundaries of several disciplines, including planning, geography, physical science, and environmental law.

CHAPTER II

LANDFILL GAS

Formation and Composition

Organic solid waste undergoes physical, chemical, and biological decomposition in landfills. During the process of organic decomposition, by-product gases are produced. The composition of landfill gas (LFG) undergoes a four phase evolutionary process as organic solid waste decomposes. This evolutionary process moves from aerobic (oxygen rich) to anaerobic (oxygen deficient) conditions as a factor of time and landfill conditions.¹⁰

The first phase is aerobic in nature and may last from several days to several weeks depending on the amount of oxygen present in the landfill at the time of solid waste placement. Oxygen present in the landfill is converted to carbon dioxide and water as the solid waste decomposes.¹¹ This process may be represented by the simple respiration formula: $C_6H_{12}O_6 + O_2 \rightarrow CO_2 + H_2O$. There is little or no formation of hydrocarbons in this first aerobic phase of landfill gas formation.

The evolutionary process continues in phase two, as organic compounds are broken down into acids, alcohols, and aldehydes by acid-forming bacteria. This phase is generally complete within 10 - 50 days of placement of solid waste

¹⁰EMCON Associates and Gas Recovery Systems, Inc., Landfill Gas: An Analysis of Options, San Jose, California, May 1981, p. 2.

¹¹Ibid., p. 2.

in the sanitary landfill.¹² Conditions in the second phase are anaerobic because free oxygen in the landfill and solid waste has been depleted. Although anaerobic conditions prevail during phase two, the phase is non-methanogenic (methane generating). Carbon dioxide is the primary by-product of the second phase of the process. Small amounts of nitrogen and hydrogen are also produced in this phase.¹³

Phase three is characterized by the initial formation of methane. Methanogenic bacteria anaerobically convert the acids formed in phase two to methane and carbon dioxide. Coincident with the initial production of methane is a reduction in the production of carbon dioxide and hydrogen.¹⁴ Completion of the third phase generally takes place within 180 - 500 days of solid waste placement in a sanitary landfill.¹⁵

Methanogenesis, the final anaerobic phase of the process, produces methane in a range of 50 - 70 percent by volume and carbon dioxide in a range of 30 - 50 percent by volume. Methanogenesis generally begins six months to three years after solid waste placement in a sanitary landfill.¹⁶ Most landfill gas (LFG) production generally occurs within fifteen years of the placement of municipal

¹²C. P. Halvadakis, A. P. Robertson, & J. O. Leckle, Landfill Methanogenesis: Literature Review and Critique, Stanford University, Stanford, California, August 1983, p. 39.

¹³James R. LaFevers, and others, The Environmental Impacts, Institutional Problems, and Research Needs of Sanitary Landfill Methane Recovery, Argonne National Laboratory, Argonne, Illinois, ANL/CNSV-TM-86, June 1981, p. 5.

¹⁴EMCON Associates and Gas Recovery Systems, Inc., Landfill Gas: An Analysis of Options, San Jose, California, May 1981, p. 3.

¹⁵C. P. Halvadakis, A. P. Robertson, and J. O. Leckle, Landfill Methanogenesis: Literature Review and Critique, Stanford University, Stanford, California, August 1983, p. 39.

¹⁶EMCON Associates and Gas Recovery Systems, Inc., Landfill Gas: An Analysis of Options, San Jose, California, May 1981, p. 3.

solid waste in a sanitary landfill, although this varies according to site-specific factors.¹⁷ Figure 2 indicates the volume of gas production over time and the four evolutionary phases of landfill gas production.

Active LFG production in a sanitary landfill is dependent on a number of site-specific conditions and factors. The generation life of landfill gas may range from very few years to hundreds of years in different environments.

Methanogenic bacteria grow slowly and are very sensitive to environmental changes.¹⁸ Rates of landfill gas production are affected by the levels of oxygen present in the landfill, solid waste composition and compaction, moisture content of the solid waste, temperature, and environmental pH.¹⁹ Landfill gas production depends on the level of activity of the microbial population.

Microbial activity is a function of nutrient availability, absence of toxic substances, and the existence of favorable environmental conditions. Table 1 indicates the most favorable environmental conditions for methanogenesis.

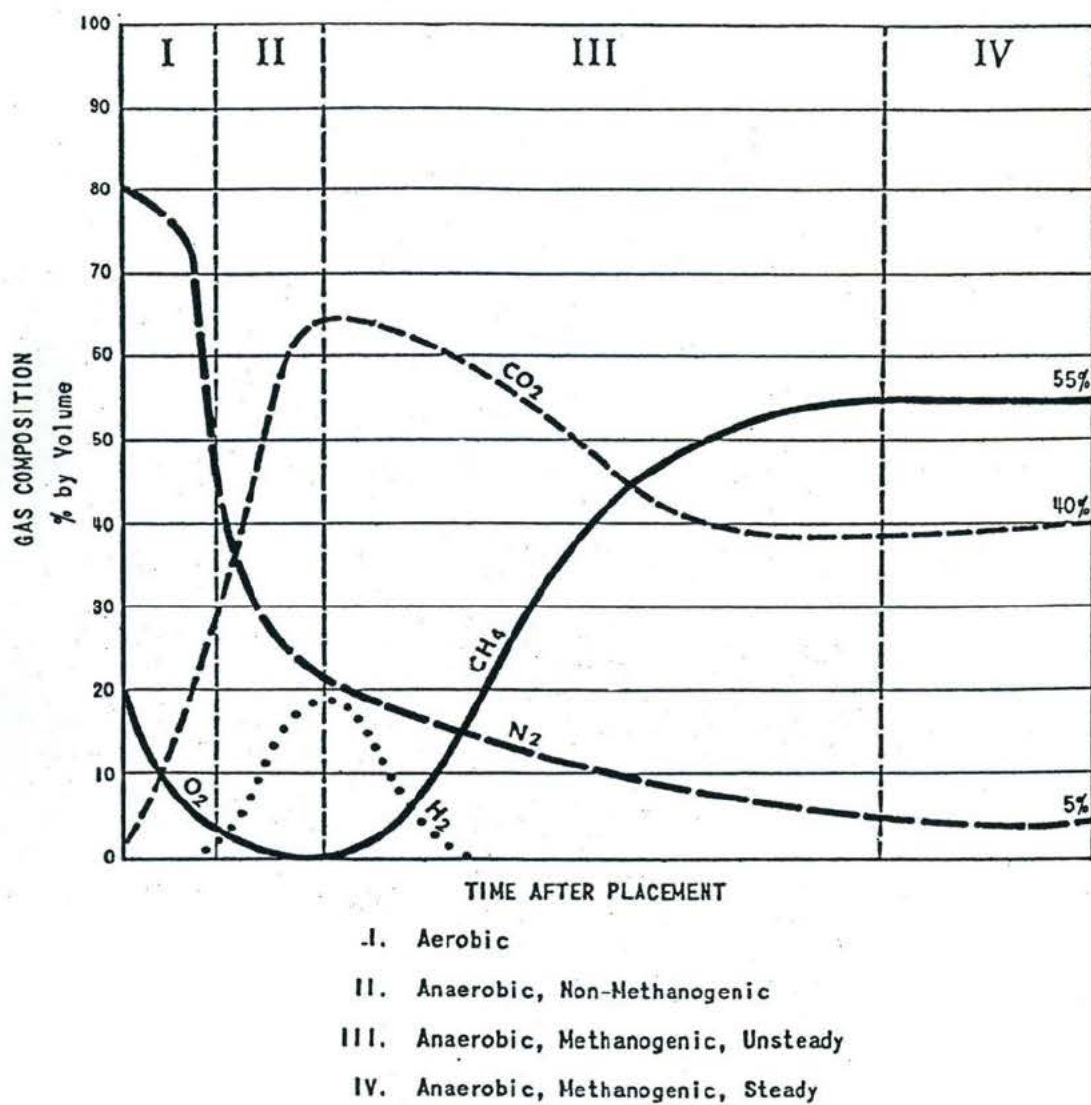
Oxygen is toxic to methanogenic bacteria and methanogenesis begins only after all free oxygen is depleted. Air infiltration into sanitary landfills will slow the rate of methanogenesis. Even small amounts of oxygen are toxic to the methanogenic bacteria. The composition of landfilled solid waste directly affects rates of methanogenesis. Methane production is stimulated by the presence of a high percentage of biodegradable solid waste. Food, garden wastes, paper, textiles, and wood fall into this category. Introduction of industrial wastes into

¹⁷James R. LaFevre, and others, The Environmental Impacts, Institutional Problems, and Research Needs of Sanitary Landfill Methane Recovery, Argonne National Laboratory, Argonne, Illinois, ANL/CNSV-TM-86, June 1981, p. 5.

¹⁸Ibid., p. 7.

¹⁹EMCON Associates and Gas Recovery Systems, Inc., Landfill Gas: An Analysis of Options, San Jose, California, May 1981, p. 3.

FIGURE 2: Evolution of Landfill Gas Composition



Source: EMCON Associates, State of the Art of Methane Gas Enhancement, 1979, p. 9

TABLE 1: Favorable Environmental Conditions for Methanogenesis

Moisture	
Sufficient nutrients (organic matter, nitrogen, phosphorus, and other nutrients)	
Absence of oxygen and other toxic materials	
pH	6.7 - 7.2
Alkalinity	> 2000 mg/l as Ca CO ₃
Organic Acids	< 3000 mg/l as CH ₃ COOH
Temperature	
mesophilic	30° - 40° C
thermophilic	50° - 55° C

Source: EMCON Associates, State of the Art of Methane Gas Enhancement,
Argonne National Laboratories, CNSV-23, p. 8

sanitary landfills may slow or decrease LFG production. A high moisture content (60 - 80 percent wet weight) in solid waste, coupled with increased temperatures, provide conditions favorable for the maximumization of landfill gas production.

Most solid waste averages only 25 percent wet weight at the time of its placement in sanitary landfills, so the initial conditions for LFG formation may be far from favorable. The pH range of 6.7 - 7.2 for optimal LFG production falls in the neutral range. Initially, most landfills exhibit acidic conditions, so optimal pH conditions for LFG formation may not occur for a number of years.²⁰

²⁰Ibid., p. 3.

Figure 3 provides a graphic representation of the interaction among the factors that are important to landfill gas production in sanitary landfills.

Of all the refuse decomposition parameters, moisture content is probably the most important, for it not only provides the aqueous environment essential to the gas production process, but also serves as a mass transport medium for nutrient and bacteria distribution in a landfill volume.²¹

This statement, found in EMCON Associates' 1979 DOE study entitled State of the Art of Methane Gas Enhancement, sums up the critical importance in landfill gas formation of the interaction represented by the graphic in Figure 3.

Landfill Gas Component Gases

Methane and carbon dioxide are the main components of landfill gas by volume, but hydrogen sulfide, ammonia, hydrogen, nitrogen and dozens of other trace gases may be present. Hydrogen sulfide may be the most important of the minor gases because of its highly corrosive nature and combustibility.²² Table 2 shows the typical major constituents of landfill gas.

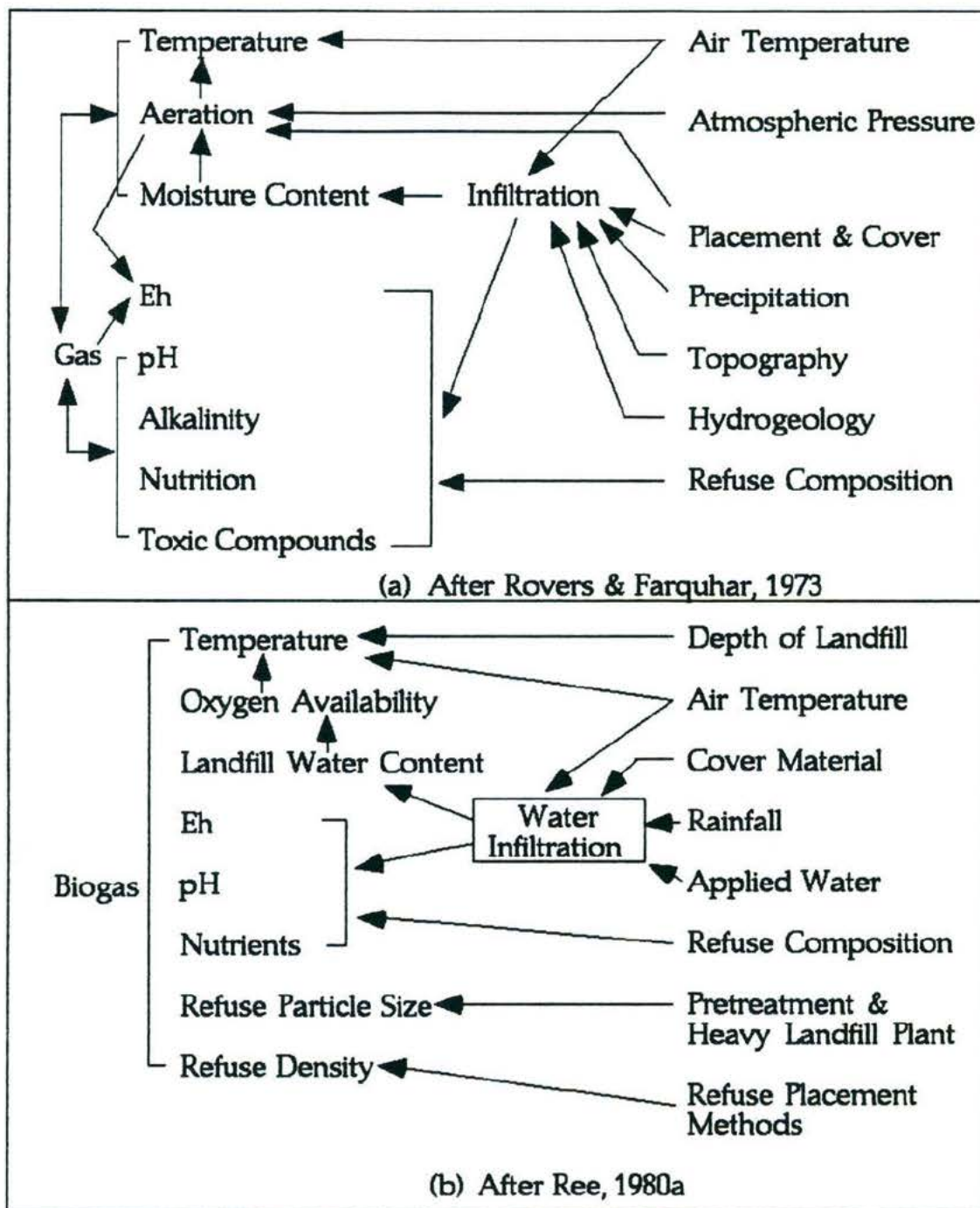
Although Table 2 indicates that landfill gas often consists of nearly equal ratios of methane and carbon dioxide, methane concentrations of up to 80 percent are sometimes found in landfills with ideal conditions for methanogenesis.²³

²¹EMCON Associates, State of the Art of Methane Gas Enhancement, prepared for Argonne National Laboratories, San Jose, California, December 1979, p. 33.

²²Ibid., p. 7.

²³James R. LaFavers, and others, The Environmental Impacts, Institutional Problems, and Research Needs of Sanitary Landfill Methane Recovery, Argonne National Laboratory, Argonne, Illinois, ANL/CNSV-TM-86, June 1981, p. 7.

FIGURE 3: Landfill Gas Production Influence Diagrams



Source: Halvadakis, and others, Landfill Methanogenesis: Literature Review and Critique, 1983, p. 43

TABLE 2: Typical Landfill Gas Components

Component	Percentage
Methane (CH ₄)	50.2
Carbon dioxide (CO ₂)	48.0
Nitrogen (N ₂)	0.86
Hydrogen (H ₂)	0.19
Oxygen (O ₂)	0.12
Toluene (C ₆ H ₅ CH ₃)	0.09
Benzene (C ₆ H ₆)	0.08
Other Hydrocarbons	0.45
Argon (Ar)	0.01

Source: James R. LaFevers, and others, The Environmental Impacts, Institutional Problems, and Research Needs of Sanitary Landfill Methane Recovery, Argonne National Laboratory, June 1981, p. 12

Conversely, some landfills with less than ideal conditions for the occurrence of methanogenesis may produce very little methane. Nearly all landfills meet the minimum conditions necessary to produce methane in small amounts. The methane content and composition of the landfill gas produced in a sanitary landfill may vary even in different areas of the same landfill, depending on refuse placement, composition and other physical factors. Thus, determining the exact composition of landfill gas that will be produced from a landfill is a difficult task.

Perhaps more critical to the resource planner's environmental assessment than the main constituent gases, methane and carbon dioxide, are the numerous

trace compounds that may be found in landfill gas. Trace compounds in landfill gas may present numerous combustion and disposal problems that must be addressed by the resource planner. The next section will examine the trace constituent components of landfill gas.

Trace Constituents of Landfill Gas

Trace constituents in raw landfill gas may create serious health and environmental impacts. Studies have identified several classes of non-methane organic compounds (NMOC) of trace constituents including "polynuclear aromatics, polyaromatic hydrocarbons, freons, alcohols, ethers, and halogenated organics."²⁴ A number of carcinogenic trace constituents of landfill gas have been identified in a municipal landfill air emission study conducted by the United States Environmental Protection Agency (EPA).²⁵ Table 3 indicates the compounds most commonly found in landfill gas.

As shown in Table 3, trichlorofluoromethane, trichloroethylene, benzene, vinyl chloride, toluene, perchloroethylene, and methylene chloride are the most commonly detected compounds in the 48 landfill sites surveyed. Table 3.0 also indicates that five of these compounds are known or suspect carcinogens.²⁶ An earlier study detected LFG concentrations of trichloromethane in the parts-per-million range, and tetrachloroethylene and trichloroethylene in the sub-ppm

²⁴ James R. LaFavers, and others, The Environmental Impacts, Institutional Problems, and Research Needs of Sanitary Landfill Methane Recovery, Argonne National Laboratory, Argonne, Illinois, ANL/CNSV-TM-86, June 1981, p. 27.

²⁵ Fred Dimmick and Alice Chow, USEPA, and Irene Kuo, Reese Howle, and John Crenshaw, Radian Corporation, USEPA Clean Air Act Regulation for Landfill Gas Emission, Environmental Protection Agency and Radian Corporation, Durham, North Carolina, 1990, p. 4.

²⁶ *Ibid.*, p. 4.

range at the Fresh Kills Landfill in New York. All of these substances have been identified by the EPA's Cancer Assessment group as being carcinogenic.²⁷

Concentrations of non-methane organic compounds measured at landfills varies widely. The EPA has not been able to find a correlation between landfill gas composition and site specific factors.

The only conclusion drawn thus far is that the highest NMOC concentrations have been measured at municipal landfills with known co-disposal histories (i.e., accepted hazardous waste prior to EPA restrictions).²⁸

Carcinogenic compounds in landfill gas composition should not prove to be a problem for landfill gas recovery projects at the many landfills that do not accept hazardous wastes or that have placed hazardous waste into segregated areas within the landfill.

Landfill Gas Generation Rates

The United States Environmental Protection Agency (EPA) has developed baseline emission estimates for non-methane organic compounds (NMOC) and methane emissions from municipal landfills in the United States as a part of its regulatory analysis for potential air emission standards. The baseline estimates are for 7,124 municipal landfills, including 1,090 municipal landfills expected to close between 1987 and 1992. Baseline emissions for 1997 are estimated to be

²⁷James R. LaFevers, and others, The Environmental Impacts, Institutional Problems, and Research Needs of Sanitary Landfill Methane Recovery, Argonne National Laboratory, Argonne, Illinois, ANL/CNSV-TM-86, June 1981, p. 27.

²⁸Fred Dimmick and Alice Chow, USEPA, and Irene Kuo, Reese Howle, and John Crenshaw, Radian Corporation, USEPA Clean Air Act Regulation for Landfill Gas Emission, Environmental Protection Agency and Radian Corporation, Durham, North Carolina, 1990, p. 4.

TABLE 3: Compounds Most Commonly Found in Landfill Gas

Chemical Name	EPA Weight Evidence	# Times Quan.	Avg. Conc Detected ppm	Highest Conc. ppm	Lowest Conc. ppm
(a)	(b)	(c)			
trichlorofluoromethane		48	0.96	11.9	0
trichloroethylene	B2	46	3.88	34	0.00615
benzene	A	45	3.64	52.2	0.00095
vinyl chloride	A	43	7.72	48.1	0
toluene		41	57.75	758	0.0493
perchloroethylene	B2	41	8.29	77	0.0035
methylene chloride	B2	36	19.31	127.5	0.00536
1,2 - dichloroethene		35	6.90	84.7	0.016
ethylbenzene		31	21.94	428	0.15
1,1,1 - trichloroethane		31	1.11	9	0.00024
1,1 - dichloroethane		27	4.24	19.5	0.05
total xylene isomers		27	18.00	70.9	0.45
dichlorodifluoromethane		25	16.44	43.99	0.19
methyl ethyl ketone		24	10.03	57.5	0
dichlorofluoromethane		24	1.40	26.11	0
chloromethane		23	3.72	44	0.09
chloroethane		23	1.97	8.25	0.026
1,2 - dichloroethane	B2	21	2.32	30.1	0.02
1,1 - dichloroethane	C	20	0.37	3.1	0.04
methyl isobutyl ketone		19	1.95	11.5	0
acetone		18	8.94	32	1
propane		18	19.41	86.5	0.63
hexane		17	7.35	20.82	1
pentane		17	8.48	46.53	0.39
chlorodifluoromethane		13	2.81	12.58	0.1
butane		13	9.27	45	0.83
carbon tetrachloride	B2	11	6.22	68.3	0.0001
1,2 - dichloropropane		10	0.35	1.8	0.02
chlorobenzene		9	2.02	10	0
1,1,2,2 - tetrachloroethane		8	1.1	4.43	0.01
chloroform	B2	8	0.35	1.56	0.001

Notes:

(a) Weight of evidence classifications indicate the likelihood that a substance is a human carcinogen. For example: A=human carcinogen; B1=probable human carcinogen based on epidemiological studies; B2=probable human carcinogen based on animal studies; C=possible human carcinogen.

(b) Based on reports from 48 individual landfill sites.

(c) Represents the average concentration of the chemical when detected.

Source: Fred Dimmick, Alice Chow, and others, USEPA Clean Air Act Regulation for Landfill Gas Emission, 1990, p. 6

300,000 Mg/yr (megagrams/year) of NMOC and 15,000,000 Mg/yr of methane. Prior to 1987, there existed more than 32,000 closed municipal landfills in the United States. These closed municipal landfills are not included in the baseline estimates.²⁹

A number of methane generation models are commonly used to estimate the landfill gas generation rate at landfills using site specific data. These models include the Palos Verde Kinetic Model, the Sheldon-Arletta Model, and the Scholl Canyon Model.³⁰ The simplest of these models and the one selected by the EPA for use in their regulatory analysis is the Scholl Canyon Model.³¹

Since the EPA has selected the Scholl Canyon Model for use in preparing its proposed standards and guidelines, this model should become both the current and future standard for estimating landfill gas generation rates in the United States.

Scholl Canyon Model

The Scholl Canyon Model is based on the assumption that the gas production rate reaches a peak rate for municipal refuse soon after placement in the landfill, ignoring a negligible lag time during which anaerobic conditions are established. The gas production is then assumed to decrease exponentially (i.e., first-order decay) as the organic fraction of the refuse decreases.³²

²⁹ Ibid., p. 10.

³⁰ USEPA, Air Emissions from Municipal Solid Waste Landfills - Background Information for Proposed Standards and Guidelines, Addendum, Draft EIS, March 1988, p. D - 1.

³¹ Ibid., p. D - 1.

³² Fred Dimmick and Alice Chow, USEPA, and Irene Kuo, Reese Howle, and John Crenshaw, Radian Corporation, USEPA Clean Air Act Regulation for Landfill Gas Emission, Environmental Protection Agency and Radian Corporation, Durham, North Carolina, 1990, p. 4.

In order to calculate a yearly landfill gas generation rate with the Scholl Canyon Model, the landfill must be divided into submasses of one year and the refuse acceptance rate must be assumed to remain constant over the life of the sanitary landfill.³³ That done, the equation for the Scholl Canyon Model may be written as:

$$Q_{CH_4} = L_0 * R * (\exp(-kc) - \exp(-kt))$$

where,

Q_{CH_4} = methane generation rate at time t , ft^3/yr
 L_0 = potential methane generation capacity of the refuse,
 ft^3/yr
 R = average annual refuse acceptance rate during the
active life, Mg/yr
 k = methane generation rate constant, yr
 c = time since landfill closure, yr
 t = time since the initial refuse placement, yr ³⁴

As one may ascertain from the Scholl Canyon Model formula, two input constants, k and L_0 , are required input parameters. In addition, the landfill age, the average landfill acceptance rate, and the time increment since landfill closure (input is 0 if landfill still active) are the input variables necessary to complete the model.³⁵

The variable k , the methane generation constant, is a measurement of the quickness with which methane generation rates decrease, once peak methane generation is attained. The higher the k value, the more rapid is the rate of refuse decomposition. A median value for k is 0.02, with a range of values from

³³Ibid., p. 8.

³⁴Ibid., p. 8.

³⁵Ibid., p. 8.

0.003 - 0.21. The EPA obtained the values for k from literature, industry experts, and from back-calculations based on flow measurement data.³⁶

Once again the major factors influencing the rate of decay of the refuse are refuse moisture content, availability of methanogenic nutrients, and landfill temperature. Higher levels of refuse moisture content generally increases the rate of methane generation, up to a level of 60 percent. Refuse moisture levels above 60 percent do not appear to increase the rate of methane generation. According to the EPA, a pH between 6.6 and 7.4 is optimal for methanogenesis. Warm temperatures within landfills do favor methane production. Ambient air temperatures may affect landfill temperature in shallow landfills. Deeper landfills exhibit fairly constant temperatures, regardless of ambient air temperatures.³⁷

L_0 represents the potential methane generation capacity of the refuse and is reported in literature in two forms, 'theoretical L_0 ' and 'obtainable L_0 '. The theoretical L_0 is determined from the cellulose content of the refuse and a gross empirical formula (based on stoichiometry) representing the chemical composition of the refuse. In comparison, the 'obtainable L_0 ' is approximated from the overall biodegradability of the refuse, assuming a conversion efficiency for specific landfill conditions. Reported values of both theoretical and obtainable L_0 range from 220 to 9450 ft^3 per Mg of refuse, with the median around 6350 ft^3 per Mg of refuse.³⁸

The Scholl Canyon Model is sensitive to the input values of k and L_0 . Site-specific field testing is the only way to accurately obtain values for k and L_0 .

³⁶Ibid., p. 8.

³⁷Ibid., p. 8.

³⁸Ibid., p. 8.

Field testing for determination of these values is extremely expensive, with costs approaching \$100,000.³⁹ A reasonable estimate of site-specific landfill gas generation rates may be obtained by using the Scholl Canyon Model and median values for k and L_0 . According to figures determined by the EPA, this method provides "an estimate within a factor of four of the two extremes."⁴⁰

Figure 4 illustrates the effect of k on landfill gas generation rates. As is evident from Figure 4, assumptions made in determining a value for k can have a large effect on the modeling done to determine landfill gas production at a landfill. When planning a commercial electricity project, extreme care should be given to the selection of the methane generation constant. The many assumptions made in determining ultimate methane production at a landfill, can, if not chosen carefully, lead one to proceed with a project that may not be viable or sound from an economic point of view.

Short Mountain Landfill Gas Analysis

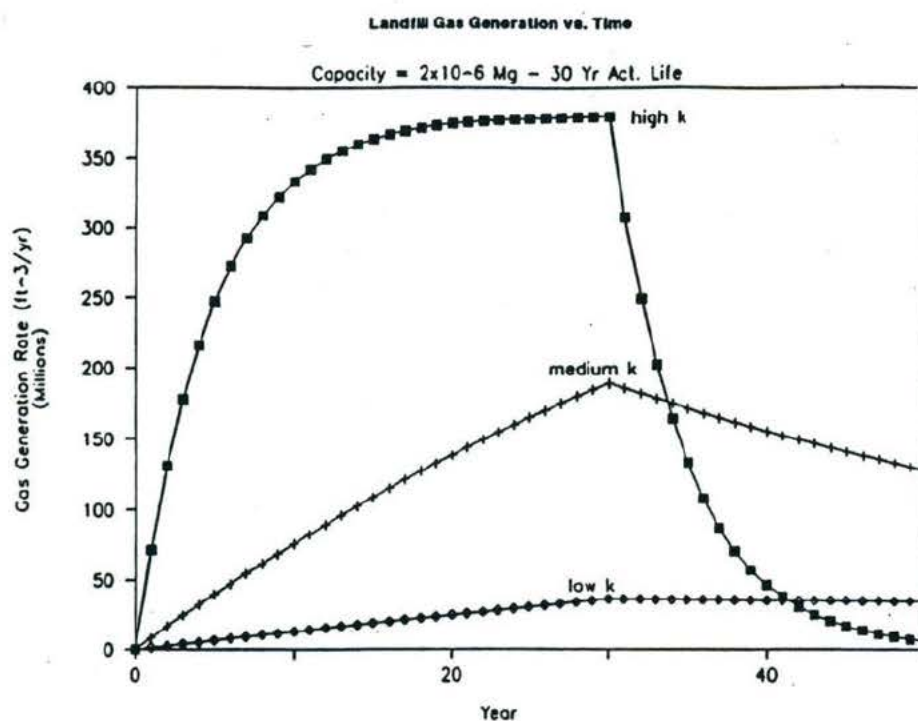
The Emerald People's Utility District (EPUD) obtained an analysis of the LFG composition at the Short Mountain Landfill in 1987, as an early step in assessing the viability of the proposed LFG to electricity project.

The EMCON Associates of San Jose, California submitted two landfill gas samples to West Coast Analytical Service, Inc. for analysis. The gas samples were analyzed on a Varian 3700 gas chromatograph equipped with a thermal conductivity detector. Gas sample #1 was also analyzed for the presence of volatile organic compounds.

³⁹Ibid., p. 8.

⁴⁰Ibid., p. 8.

FIGURE 4: Effect of k On Landfill Gas Generation Rate Modeling Estimate



Source: Fred Dimmick, Alice Chow, and others, USEPA Clean Air Act Regulation for Landfill Gas Emissions, 1990, p. 9

The results of the gas analysis, as reported by EMCON Associates, are shown in Table 4. A methane concentration of 55 percent of the total landfill gas volume was found in the gas analysis sample taken at the Short Mountain Mountain Landfill. The carbon dioxide concentration in the landfill gas analysis sample taken at the Short Mountain Landfill was 36 percent of the total gas volume.⁴¹

Table 5 indicates the results of the analysis for the presence of volatile organic compounds. An examination of Table 5 reveals no detectable levels of possibly toxic or carcinogenic volatile organic compounds (non-methane). Short Mountain is a relatively young and well-segregated landfill, thus, the analysis is as it should be. Waste management techniques at the Short Mountain Landfill should prevent any problems with toxic and carcinogenic compounds in the composition of the landfill gas extracted from the landfill.

Short Mountain Landfill Gas Production

The EMCON Associates performed extensive modeling of the average landfill gas production rate at the Short Mountain Landfill, as a part of a preliminary planning assessment by Emerald People's Utility District (EPUD). The model used by EMCON Associates yields results similar to those obtained from the Environmental Protection Agency-preferred Scholl Canyon Model. EMCON's modeling technique was developed in-house by the firm.⁴²

⁴¹ EMCON Associates, Laboratory Report, prepared for Emerald PUD, April 29, 1987 p. 2.

⁴² EMCON Associates, State of the Art of Landfill Gas Recovery, prepared for Argonne National Laboratories, ANL/CNSV-TM-85, July 1981, p. 23.

TABLE 4: Short Mountain Landfill Gas Analysis

<u>Compound</u>	<u>Volume Percent</u>		<u>Detection Limit</u>
	<u>Sample #1</u>	<u>Sample #2</u>	
Oxygen and/or Argon	1.77	8.40	0.01
Nitrogen	6.46	27.7	0.01
Carbon Monoxide	ND	ND	0.01
Methane	55.4	38.4	0.01
Carbon Dioxide	36.4	25.5	0.01

Note: ND = Not Detected

Note: Date Analyzed: 4/20/87

Source: Adapted from EMCON Associates, Laboratory Report, Prepared for Emerald People's Utility District, April 29, 1987, p. 2

Sufficient LFG production to support Emerald PUD's proposed electricity generation project at the Short Mountain Landfill is projected through the year 2030, giving the utility a 40 year life expectancy for the project. Figures obtained from the modeling done by the EMCON Associates show that the utility can expect the average landfill gas production rate at the Short Mountain Landfill to peak during a two year period, 2006-2007, and exhibit a steady decline thereafter.⁴³ Figure 5 illustrates the Short Mountain Landfill average landfill gas production rate and the probable LFG recovery rate, as modeled by EMCON.

⁴³EMCON Associates, Landfill Gas Recovery Feasibility Study, Short Mountain Landfill, Lane County, Oregon, prepared for Emerald People's Utility District, San Jose, CA, July 1987, p. 5.

TABLE 5: Non-methane Organic Compounds - Short Mountain Landfill

Analysis Type: Gas Phase Volatile Compounds		
Organics Analysis Data Results		
Compound	Conc: PPM (V/V)	Detection Limit
Chloromethane	ND	1.
Bromomethane	ND	1.
Vinyl Chloride	ND	1.
Chloroethane	ND	1.
Methylene Chloride	ND	1.
Acetone	ND	1.
Acrolein	ND	1.
Acrylonitrile	ND	1.
Carbon Disulfide	ND	1.
1, 1 - Dichloroethene	ND	1.
1, 1 - Dichloroethane	ND	1.
Trans - 1, 2 Dichloroethylene	ND	1.
Cis - 1, 2 Dichloroethylene	ND	1.
Tetrahydrofuran	ND	1.
Dichlorodifluoromethane	ND	1.
Trichlorofluoromethane	ND	1.
Freon - TF	ND	1.
Ethylene Dibromide	ND	1.
1, 4 - Dioxane	ND	1.
1, 2 - Dibromo-3-chloropropane	ND	1.
Chloroform	ND	1.
1, 2 - Dichloroethane	ND	1.
2 - Butanone	ND	1.
1, 1, 1 - Trichloroethane	ND	1.
Carbon Tetrachloride	ND	1.
Vinyl Acetate	ND	1.
Bromodichloromethane	ND	1.
1, 1, 2, 2 - Tetrachloroethane	ND	1.
1, 2 - Dichloropropane	ND	1.
Trans - 1, 3 - Dichloropropene	ND	1.
Trichloroethene	ND	1.
Chlorodibromomethane	ND	1.
1, 1, 2 - Trichloroethane	ND	1.
Benzene	ND	1.
Cis - 1, 3 - Dichloropropene	ND	1.
2 - Chloroethylvinyl Ether	ND	1.

TABLE 5: Continued

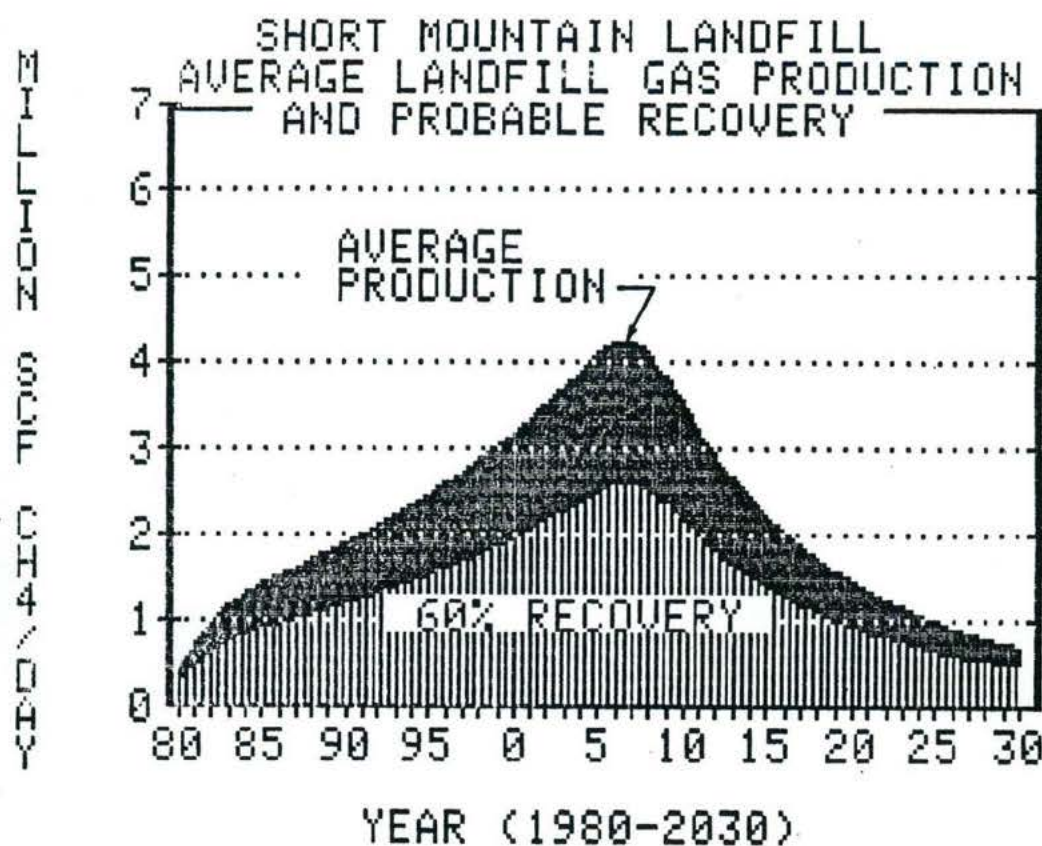
Analysis Type: Gas Phase Volatile Compounds

Organics Analysis Data Results

Compound	Conc: PPM (V/V)	Detection Limit
Bromoform	ND	1.
2 - Hexanone	ND	1.
4 - Methyl - 2 - Pentanone	ND	1.
Tetrachloroethene	ND	1.
Toluene	ND	1.
Chlorobenzene	ND	1.
Ethylbenzene	ND	1.
Styrene	ND	1.
Total Xylenes	ND	1.
M - Chlorotoluene	ND	1.
1, 3 - Dichlorobenzene	ND	1.
1, 4 - Dichlorobenzene	ND	1.
1, 2 - Dichlorobenzene	ND	1.
Naphthalene	ND	1.

Source: Adapted from EMCON Associates, Laboratory Report, prepared for the Emerald People's Utility District, April 29, 1987, pp. 4-5

FIGURE 5: Average Landfill Gas Production and Probable Recovery



Source: EMCON Associates, Landfill Gas Recovery Feasibility Study, Short Mountain Landfill, Lane County, Oregon, San Jose, CA, Prepared for Emerald People's Utility District, July 1987, p. 5

The Short Mountain Landfill's average landfill gas production rate in the years 2006 and 2007 is projected to be 4.241 MMcfd (million cubic feet per day), declining to less than 0.8 MMcfd by the year 2030.⁴⁴ The Emerald PUD's financial analysis of the project shows an average landfill gas production rate of 1.990 MMcfd during 1991, the anticipated date for the project to begin landfill gas recovery and electricity generation.⁴⁵

Using a landfill gas recovery factor of 60 percent⁴⁶, the project will recover a maximum of 2.757 MMcfd of landfill gas in the years 2006 and 2007. LFG recovery is projected to be 1.294 MMcfd in 1991. Assuming an average methane content in the landfill gas of 50 percent⁴⁷, the project will recover 0.711 MMcfd of methane from the Short Mountain Landfill in 1991 and a maximum of 1.516 MMcfd of methane in the years 2006 and 2007.⁴⁸

⁴⁴Ibid.

⁴⁵Emerald People's Utility District, Short Mountain Landfill Gas Utilization Analysis, Eugene, Oregon, January 24, 1990, p. 1.

⁴⁶EMCON Associates, Landfill Gas Recovery Feasibility Study, Short Mountain Landfill, Lane County, Oregon, prepared for Emerald People's Utility District, San Jose, CA, July 1987, p. 5

⁴⁷Emerald People's Utility District, Short Mountain Landfill Gas Utilization Analysis, Eugene, Oregon, January 24, 1990, p. 1.

⁴⁸Ibid.

CHAPTER III

PROJECT SITE ASSESSMENT

Assessment Factors

A site assessment for the landfill location and design is an essential part of the preliminary planning process for a landfill gas recovery to electricity generation project. Knowledge gained from the assessment may play an important role in determining the appropriateness of the landfill site for an electricity generation project and ultimately, the success or failure of the entire project. The landfill site's physiography, climate, air and water quality, fish and wildlife, and the size and physical layout of the existing landfill are several geographical factors that must be included in this evaluation. Potential air and water pollution problems may be identified as a result of the preliminary site assessment. Environmental impacts that are recognized early in the site assessment process may be more effectively dealt with and are far less likely to derail the project later in the implementation phase. Air quality in the airshed surrounding the project site may well be the single most critical factor involved in siting a landfill gas to electricity generation facility. Poor air quality may prevent the siting of a facility of this kind.

Again in this chapter, the Short Mountain Landfill Methane-to-Electricity Generation Project will be used to illustrate the process of performing an environmentally sound site assessment prior to the implementation phase of the project. Each individual project site presents a unique set of problems to be

identified and dealt with. A knowledgeable resource planner may, however, effectively surmount these problems by using a sound assessment and planning process.

Physiography

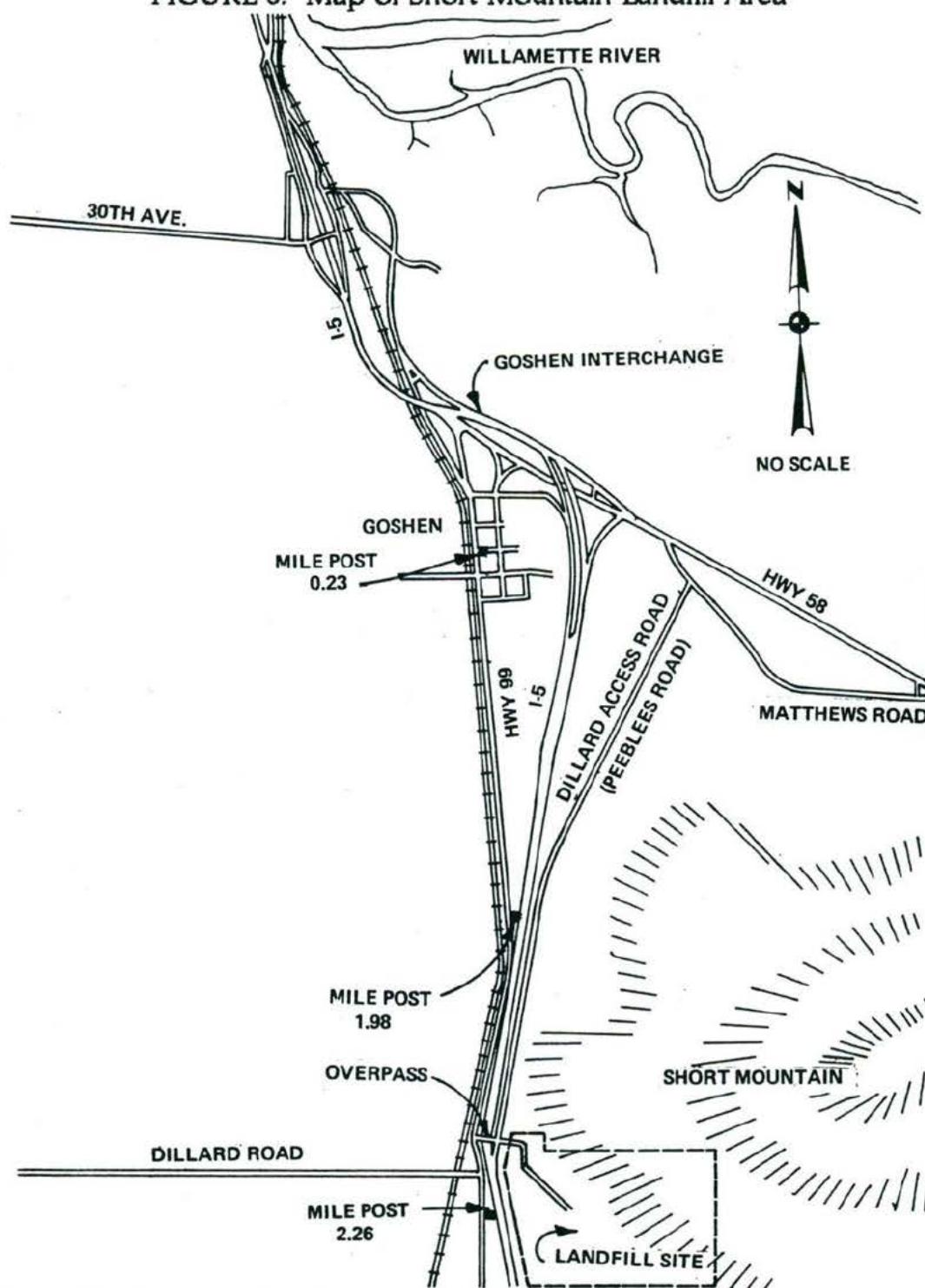
Site assessment of the proposed project must begin with a brief description of the geographical location and physiography of the landfill site and the surrounding area. The Short Mountain Landfill is located on the southern flank of Short Mountain in central Lane County, Oregon, near the cities of Eugene and Springfield. Short Mountain rises above the valley floor at the southern end of the Willamette Valley, near the confluence of Camas Swale Creek and the Coast Fork of the Willamette River. The foothills of the Coast Range Region stretch to the west of the landfill area and the foothills of the Western Cascades Region are located to the east.⁴⁹ Short Mountain's geographic coordinates are: Latitude North 43:58:16 (Deg:Min:Sec) and Longitude West 122:59:23 (Deg:Min:Sec).⁵⁰ Figure 6 shows the geographical location of the Short Mountain Landfill in Lane County, Oregon.

The rural 584 acre Short Mountain Landfill site is naturally isolated from the Eugene-Springfield metropolitan area, which is located approximately 8.5 miles to the north and west. Local terrain surrounding the landfill to the north and west serves as a natural buffer between the two cities and the landfill location. Creswell, Oregon, a small, rural community, lies approximately 1 mile

⁴⁹James E. Meacham, *Atlas of Lane County, Oregon*, Lane County, Lane Council of Governments, and the University of Oregon, Eugene, Oregon, 1990, pp. 4-5.

⁵⁰*Ibid.*, p.67.

FIGURE 6: Map of Short Mountain Landfill Area



Source: Department of Environmental Management, Environmental Assessment: Short Mountain Landfill, Lane County, Oregon, Solid Waste Division, Eugene, Oregon, January 1976, p. XI-4

the south of the landfill. Pleasant Hill, Oregon, another rural community, is also situated about 1 mile from the landfill, directly to the northeast of the site. The Short Mountain Landfill location, bounded on the north and east by Short Mountain, is effectively isolated from the Pleasant Hill area. Interstate 5 borders the landfill location to the west.

The 584 acre landfill site lies at the base of Short Mountain and includes nearly 1200 feet of the Coast Fork of the Willamette River and a portion of Camas Swale Creek, from its confluence with the Coast Fork to approximately 4500 feet upstream. The northwest property line of the landfill parcel borders Interstate 5 for about 4000 feet. Short Mountain rises to a height of 1106 feet on the north property border and slopes steeply from an elevation of 600 feet. Below elevation 600 feet, the land slopes gently in the direction of Camas Swale Creek. For the most part, the landfill's solid waste disposal area lies in the gently sloping area toward Camas Swale Creek, between elevations 500 feet and 600 feet.⁵¹

Climate

The climate of the Short Mountain Landfill site is dominated by moist, mild air off the Pacific Ocean. Annual precipitation, taken from a 30 year average as measured at the Eugene climatological weather data station, is 42.56 inches.⁵² "Rainfall is the primary source of precipitation in Lane County, Oregon."⁵³ The precipitation is unevenly distributed throughout the year, with 15.18 or 35

⁵¹Department of Environmental Management, Environmental Assessment: Short Mountain Landfill, Lane County, Oregon, Solid Waste Division, Eugene, Oregon, January 1976, pp. I-4,5.

⁵²Meacham, Atlas of Lane County, Oregon, p. 6.

⁵³Ibid., p. 6.

percent of the total coming in the months of December and January. During the months of July and August, less than 2 percent of the annual precipitation or 0.84 inches falls.⁵⁴ Prevailing winds in Lane County at the Eugene station are from the north (137 days), south (119 days), and southwest (63 days).⁵⁵

Precipitation and the direction of prevailing winds play an important role in the siting of an electricity generation project such as the Emerald PUD's Short Mountain project. Modeling of potential air pollution by the project, a key aspect of obtaining the necessary Air Contaminant Discharge Permit, is dependent on these factors. The permit process will be discussed in a later chapter.

Climate may also play an important role in landfill gas production. The moist conditions found in western Oregon and specifically at the Short Mountain Landfill site are ideal for the methanogenic process to take place. In other words, more methane will be produced at the landfill because of the high moisture content in the solid waste. This process was more fully discussed in Chapter 2.

Geology

The following information on the geology at the Short Mountain Landfill site is taken from a May 1990 engineering study performed by Russ Fetrow Engineering, Inc. of Eugene, Oregon.

The bedrock geology at the Short Mountain site consists primarily of Tertiary non-marine sedimentary and pyroclastic rocks which are intruded by Tertiary basaltic dikes and sills.

⁵⁴Ibid., p. 6.

⁵⁵Department of Environmental Management, Environmental Assessment: Short Mountain Landfill, Lane County, Oregon, Solid Waste Division, Eugene, Oregon, January 1976, p. XIII-1.

The slopes of Short Mountain and adjacent hills are largely covered with varying thicknesses of colluvium consisting mostly of scattered basaltic or pyroclastic boulders in a clayey, sandy matrix. Recent fluvial deposits overlie the weathered Tertiary bedrock along the flood plains of Camas Swale Creek. At the base of the mountain, the floodplain deposits interfinger with indistinct alluvial fans deposited by the small creeks originating along the southern slopes of Short Mountain.⁵⁶

Russ Fetrow Engineering, Inc. also tested samples from six excavation test pits at the landfill site to obtain data on the distribution of geologic materials and the geotechnical properties of the materials. Two of these samples were taken from the weathered Tertiary bedrock underlying the 500 year floodplain of Camas Swale Creek, one sample was a combination of clayey channel sands and the underlying weathered sandstones, and two samples were taken from the floodplain clays.⁵⁷ The results of the tests are quoted in the following passage from the engineering study.

The two samples of floodplain deposits were classified as Clay and Silty Clay. The two samples of weathered sandy facies of the Fisher Formation were classified as Clayey Sand and Silty, Clayey Sand. The sample representing a mixture of the weathered bedrock with the floodplain deposits were classified as Sandy Clay. Permeability test results of the samples indicate a range of permeability in the material between 1.112×10^{-6} and less than 1×10^{-8} cm/sec. (centimeters per second), with the lowest values in the floodplain clays. The low permeability values indicate that the clays and the silty clays found on the Camas Swale Creek 500 year floodplain are a valuable resource for bottom liners and final cover.⁵⁸

⁵⁶Russ Fetrow Engineering, Inc., Engineering Report for the Short Mountain Landfill, Lane County, Eugene, Oregon, May 1990, p. iv.

⁵⁷Ibid.

⁵⁸Ibid.

The slopes of Short Mountain are covered with colluvium (weathered bedrock). The material, consisting mostly of basaltic and pyroclastic boulders in a clayey, sandy matrix, varies in thickness from 1 to 4 feet. Tests done for the initial landfill study in 1976 indicate that the colluvium may reach a thickness of 8.5 feet. Alluvium, the recent fluvial deposits, overlies the weathered bedrock along the floodplain of Camas Swale Creek. Near the base of the mountain, the floodplain deposits interfinger with alluvial fans deposited by creeks originating on the southern slopes of Short Mountain. Fine-grained flood deposits of Camas Swale Creek and coarse-grain channel deposits from Camas Swale Creek and the Coast Fork of the Willamette River make up the alluvium.⁵⁹

Accurate geological information is extremely critical to the planning process for a landfill gas to electricity project. In the process of extracting landfill gas from the landfill, landfill gas condensate and leachate also enters the landfill gas collection system. Landfill gas condensate and leachate must be separated from the gas stream and disposed of prior to the combustion of landfill gas in electricity generation equipment. The low permeabilities of the soils at Short Mountain will enable the Emerald People's Utility District electricity generation project to return any landfill gas condensate and leachate collected by the landfill gas collection system to the landfill's leachate lagoons via Short Mountain's existing leachate collection system. Otherwise, the landfill gas condensate and leachate collected at the electricity generation site would have to be collected, stored, and then transported to another location for treatment and proper disposal.

⁵⁹Ibid., pp. 5-5, 5-6.

Water Quality

Data obtained from the monitoring wells at the Short Mountain Landfill shows that the groundwater in the coarse-grained Tertiary sedimentary substrata is of good quality. Groundwater in the fine-grained Tertiary mudstones and the clayey sandstones is of poorer quality and has a high degree of salinity. There has been no determination of a definitive cause for this poor groundwater quality, but it may be that the groundwater quality is influenced by Tertiary marine sediments of the Eugene Formation to the west of the landfill location.⁶⁰

"Monitoring well data indicate that the overall groundwater flow direction at the site is to the south, off Short Mountain."⁶¹ The flow of groundwater off the mountain is across the active landfill solid waste disposal cells, toward Camas Swale Creek. More importantly, the groundwater flow is in the direction of the landfill's leachate collection lagoons and water quality monitoring wells. The Emerald PUD's electricity generation project will be located on the north side of the landfill site, on the southern slope of Short Mountain. Any leakage of landfill gas condensate or other materials will enter the groundwater above the landfill and flow to the south. This will allow effective monitoring of any impact on groundwater quality by the project in the landfill's water quality monitoring wells.

Russ Fetrow Engineering, Inc. also performed a water balance test to determine if leachate leakage from the landfill or the leachate collection lagoons is connected to the high degree of groundwater salinity found in the landfill's

⁶⁰Ibid., p. v.

⁶¹Ibid., p. v.

monitoring wells. Leachate collected from the landfill is treated and then held in the lagoons for disposal through evapotranspiration.⁶² As a result of the water balance test, it was determined that there is no leakage from the primary leachate lagoon and only minimal leakage from the secondary leachate lagoon. There is no concrete evidence of any leachate leakage into the groundwater supply under the landfill location.

The chemical signature of leachate found in the collection lagoons differs significantly from that of the groundwater tested in the water quality monitoring wells. Therefore, it is the opinion of the firm that leachate leakage is not the source of the high salinity content of the groundwater found in the fine-grained mudstones and clayey sandstones underlying the landfill site. Geologic data collected for the firm's study indicate that the high salinity content signature of groundwater at the Short Mountain Landfill location may be presumed to be a naturally occurring phenomena.⁶³

Water quality should not be a limiting factor in the siting of the Emerald PUD's electricity generation project. So long as the existing landfill facilities can adequately handle leachate production at the landfill and the landfill gas condensate returned to the landfill by the electricity generation project, the potential for an adverse impact on water quality at the site is minimal.

⁶²Department of Environmental Management, Environmental Assessment: Short Mountain Landfill, Lane County, Oregon, Solid Waste Division, Eugene, Oregon, January 1976, p. X-2.

⁶³Russ Fetrow Engineering, Inc., Engineering Report for the Short Mountain Landfill, Lane County, Eugene, Oregon, May 1990, p. v.

Air Quality

Air quality at the rural landfill site is generally good. However, the nearby Eugene-Springfield metropolitan area has been designated as a Group I non-attainment area for PM₁₀ (particulate matter less than 10 microns in size) ambient air quality standards.⁶⁴ The landfill site does not fall within the Eugene-Springfield Air Quality Maintenance Area and therefore is not subject to the greater degree of PM₁₀ control necessary in a designated Group I non-attainment area.⁶⁵

In addition to PM₁₀, there are five additional national standards for outdoor air pollutants. National ambient air quality standards for carbon monoxide, nitrogen dioxide, sulfur dioxide, ozone, and lead have been set by the Environmental Protection Agency under the Clean Air Act. The State of Oregon has adopted the standards with some modification. State standards may be more stringent than the national standards, but not less stringent. The ambient air quality standards are shown in Table 6.

Rules promulgated by the EPA require areas to monitor (test) air for air pollutants that from historical data and local population distributions appear to warrant such testing.⁶⁶ The PM₁₀ pollutants continue to be the pollutant of most concern in Lane County, followed by carbon monoxide (CO). The Eugene-Springfield area is currently listed as a non-attainment area for carbon monoxide, but the Lane Regional Air Pollution Authority (LRAPA) has applied to have the

⁶⁴Lane Regional Air Pollution Authority, 1988-1990 Air Quality Report, Springfield, Oregon, 1990, p. 12.

⁶⁵LRAPA, Title 34 - Air Contaminant Discharge Permits, May 14, 1985, Table A.

⁶⁶LRAPA, 1988-1990 Air Quality Report, Springfield, Oregon, 1990, p. 1

TABLE 6: Ambient Air Quality Standards

Pollutant	Averaging Time	Federal Standard	State Standard
PM ₁₀	AAM 24 hours	50 µg/m ³ 150 µg/m ³	50 µg/m ³ 150 µg/m ³
Total Suspended PM *	AAM 24 hours	NA NA	60 µg/m ³ 150 µg/m ³
Ozone	1 hour	0.12 ppm	0.12 ppm
Carbon Monoxide	8 hours 1 hour	9 ppm 35 ppm	9 ppm 35 ppm
Sulfur Dioxide	AAM 24 hours 3 hours	0.03 ppm 0.14 ppm 0.5 ppm	0.02 ppm 0.10 ppm 0.5 ppm
Nitrogen Dioxide	AAM	0.053 ppm	0.053 ppm
Lead	Calendar Quarter	1.5 µg/m ³	1.5 µg/m ³

Note: AAM = Annual Arithmetic Mean
 µg/m³ = micrograms of pollutant per cubic meter of air
 ppm = parts per million

Note: * The federal TSP standard was dropped in 1987. Oregon retained the state standard.

Source: Oregon Department of Environmental Quality, Air Quality Control Division, 1989 Oregon Air Quality Annual Report, p. 19

area listed as being in CO attainment after several years of no violations of the carbon monoxide standard.⁶⁷ Ozone (O₃) is also an air pollutant of concern to the county. The Lane Regional Air Pollution Authority continuously monitors the

⁶⁷Ibid., p. 6.

air in the county for concentrations of these three pollutants. A mix of meteorology, topography and the local sources of particulate matter, carbon monoxide, and ozone combine to make these pollutants of continuing concern to the area. Lead concentrations are also monitored on a continuing basis and sulfur dioxide atmospheric levels have been tested in the recent past. Historically, ambient air concentrations of lead and sulfur dioxide have been measured at very low levels in Lane County.⁶⁸

Meteorology and the topography of the Willamette Valley area of Lane County play a key role in contributing to the ambient air pollution problems that continue to plague this area. The following excerpt, taken from LRAPA's 1988-1990 AIR QUALITY REPORT, explains the effect that meteorology and topography combine to have on the southern Willamette Valley portion of western Oregon.

The Eugene-Springfield metropolitan area is surrounded on three sides by elevated terrain, which can restrict horizontal movement of air. In addition, cold air can become trapped in the valley with warm air aloft, creating temperature inversion conditions. This combination causes periods of air stagnation which trap pollutants near the ground. It is not uncommon for these conditions to occur over a period of several days. The worst conditions tend to occur in the winter months. The inversion will be broken and atmospheric cleansing will take place when a storm front passes through the area.⁶⁹

Temperature inversions, cool air trapped under warm air above, may create air pollution problems in the Willamette Valley at any time, but they most frequently occur during the winter months. During periods of air stagnation

⁶⁸Ibid., p. 1.

⁶⁹Ibid., p. 2.

caused by such temperature inversions, concentrations of air pollutants in the area may climb dramatically.⁷⁰

Although the topography surrounding the landfill site is such that the location is separated from the metropolitan area for purposes of air quality regulation, the close proximity of the Short Mountain Landfill to the urban area brings the Emerald PUD's electricity generation project under closer scrutiny by the Lane Regional Air Pollution Authority. The atmospheric conditions that create air pollution problems to the north of the landfill site may from time to time also create the same problems in the area surrounding Short Mountain. An industrial source of air pollutants such as the Emerald PUD's landfill methane to electricity project may influence air quality in the Eugene-Springfield metropolitan area due to frequent seasonal changes in the direction of prevailing winds over this portion of Lane County. Subsequent deterioration of air quality in the adjacent urban area by the Emerald PUD's project, especially due to the pollutants PM₁₀, carbon monoxide, and NO_x (a project air pollutant contributing to the formation of ozone), must be taken into account in the electricity generation facility's site assessment process.

Fish and Wildlife

Several species of large and small mammals, upland game birds, and non-game birds inhabit the lands surrounding the landfill. Nearby Camas Swale Creek and the Coast Fork of the Willamette River contain a variety of species of fish. There are no rare, threatened, or endangered species of fish or wildlife in the area of the Short Mountain Landfill. Five species of Columbia Basin salmon

⁷⁰Ibid.

are now being studied for listed status under the Endangered Species Act. None of the salmon species in the landfill area are among the five being studied.

The Coast Fork of the Willamette River contains salmon, steelhead, trout, bass, and crappie. Coho and chinook salmon, and steelhead are not resident species in the river, but do use the waterway for migration and spawning. Rainbow and cutthroat trout are cold water species resident in the river year round. Warm water species resident in the river are large mouth and small mouth bass, bluegill sunfish, white crappie, and bullhead catfish.⁷¹ Camas Swale Creek is severely limited in the amount of fish species present in the creek. Relatively high water temperatures and low stream flow due to upstream water withdrawals for irrigation limit the resident fish species to suckers and squawfish for 5 miles upstream from its confluence with the Coast Fork of the Willamette River. The landfill site is located at approximately river mile 0.5 on Camas Swale Creek.⁷²

Blacktail deer, fox, bobcat, coyote, beaver, muskrat, and mink are among the several mammals that inhabit the area surrounding the landfill and electricity generation project.

The Southern Willamette Ornithological Club has identified, on or near Short Mountain, 83 species of birds, including songbirds, Kesterels (Sparrow Hawk), Cooper's Hawk, Sharpshinned Hawk, Redtail Hawk, Turkey Vulture, Blue and Ruffed Grouse, California and Mountain Quail, and California and Ringneck Pheasants.⁷³

⁷¹Department of Environmental Management, Environmental Assessment: Short Mountain Landfill, Lane County, Oregon, Solid Waste Division, Eugene, Oregon, January 1976, p. VIII-5.

⁷²Ibid.

⁷³Ibid., p. VIII-3.

TABLE 7: Short Mountain Landfill Area Fish and Wildlife

<u>Common Name, Genus, Species</u>		
<u>Wildlife</u>	<u>Fish</u>	<u>Birds</u>
<u>Black-tailed Deer</u> (Odocoileus hemionus columbianus)	<u>Coho Salmon</u> (Oncorhynchus kisutch)	<u>Kestrels-Sparrow Hawk</u> (Falco sparverius)
<u>Red Fox</u> (Vulpes vulpes)	<u>Chinook Salmon</u> (Oncorhynchus tshawytscha)	<u>Cooper's Hawk</u> (Accipiter cooperii)
<u>Bobcat</u> (Lynx rufus)	<u>Steelhead-sea run trout</u> (Salmo gairdneri gairdneri)	<u>Sharpshinned Hawk</u> (Accipiter striatus)
<u>Coyote</u> (Canis latrans)	<u>Rainbow Trout</u> (Salmo gairdneri)	<u>Redtailed Hawk</u> (Buteo jamaicensis)
<u>Beaver</u> (Castor canadensis)	<u>Cutthroat Trout</u> (Salmo clarki clarki)	<u>Turkey Vulture</u> (Cathartes aura)
<u>Muskrat</u> (Ondatra zibethica)	<u>Largemouth Bass</u> (Micropterus salmoides)	<u>Blue Grouse</u> (Dendragapus obscurus)
<u>Mink</u> (Lutreola vison)	<u>Smallmouth Bass</u> (Micropterus dolomieu)	<u>Ruffed Grouse</u> (Bonasa umbellus)
	<u>Bluegill Sunfish</u> (Lepomis macrochirus)	<u>California Quail</u> (Lophortyx californicus)
	<u>White Crappie</u> (Pomoxis annularis)	<u>Mountain Quail</u> (Oreortyx pictus)
	<u>Bullhead Catfish</u> (Ictalurus nebulosus)	<u>California Pheasant</u> (Phasianus californicus)
	<u>Suckers</u> (Catostomus platyhynchus)	<u>Ringneck Pheasant</u> (Phasianus colchicus)
	<u>Squawfish</u> (Ptychocheilus oregonensis)	

Sources: Adapted from Burton, University Dictionary of Mammals of the World; 1962, Bond, Keys to Oregon Freshwater Fisheries, 1973; Terres, The Audubon Society Encyclopedia of North American Birds, 1980

Table 7 summarizes the fish, birds, and wildlife found near Short Mountain Landfill, with the common name, genus, and species listed for each.

The 1976 environmental assessment performed to analyze the possible significant impacts of the landfill operation predicted that the landfill would have minimal significant impacts on the area's fish and wildlife. The environmental assessment recommended that initial site design be done with the intent of minimizing these significant impacts by careful attention to environmental guidelines for landfill construction, particularly impermeable liners and proper waste covering, and other remedial measures, such as the construction of buffer zones surrounding perimeter of the landfill site.⁷⁴ Wildlife capable of adapting to the landfill operation have probably done so, while others may have migrated through the outer buffer zones to areas away from the landfill operation. Fisheries in the Coast Fork of the Willamette River are in a recovery phase, primarily due to cessation of upstream logging, habitat recovery, and a stocking program.⁷⁵ The 1990 engineering study by Russ Fetrow Engineering indicates that the landfill operations are operating under a valid State of Oregon, Department of Environmental Quality solid waste disposal permit⁷⁶, but no further studies have been done to document the migration of wildlife or the effects of the landfill on fish and wildlife populations and habitat.

With the possible exception of an increased level of background noise created by the operation of the electricity generation equipment, the Emerald PUD's project should have no additional significant impact on wildlife and fish populations or habitat. Impacts from the construction of the project may have a

⁷⁴Ibid., p. VIII-2.

⁷⁵Ibid., pp. VIII-2 - VIII-7.

⁷⁶Russ Fetrow Engineering, Inc., Engineering Report for the Short Mountain Landfill, Lane County, Eugene, Oregon, May 1990, p. v.

short term effect on the populations and habitat, but it will be temporary in nature.

Landfill Site Plan

The construction and placement of EPUD's landfill methane-to-electricity project is being carefully coordinated with future development and solid waste fill placement plans at the Short Mountain Landfill. The siting and design of the generating facility will help prevent future problems with transporting landfill gas over long distances to the facility's internal combustion engines.

Figure 7 provides a map of the existing site topography and the active fill areas at the Short Mountain Landfill. Phases I and II, as indicated in Figure 7, are the active fill areas at Short Mountain. The landfill areas labeled as Phases III - VI in Figure 7 will become active fill areas in Lane County's future development plans.

The Lane County Waste Management Division of the Department of Public works recently finished filling the easterly portion of the landfill (Phase I) and is beginning to place solid waste over a previously filled (older) section of the landfill (Phase II), directly to the west of the Phase I fill area. The Emerald PUD's original design plans for the landfill gas recovery system in the older Phase II fill area anticipated completion of the landfill gas recovery project prior to any additional deposition of solid waste in the Phase II section of the landfill. Delays in hiring a contractor to construct the utility's project caused Lane County to proceed with its scheduled time table for Phase II solid waste deposition prior to installation of the landfill gas recovery system. Now, the project must undergo further design modifications to adapt the landfill gas recovery system to

Lane County's Phase II solid waste disposal plans. The landfill gas recovery system design process will be fully addressed in Chapter IV.

The Emerald People's Utility District plans to place their electricity generation facility next to the current fill area at the Short Mountain Landfill. Several internal combustion engines, electricity generators, electricity switching equipment, transformers, gas compression equipment, and the gas separation and clean-up facilities will all be located at this site, directly adjacent to and just north of the Phase II fill area. The proposed site for the project's electricity generation facilities is shown on the Short Mountain Landfill map in Figure 7.

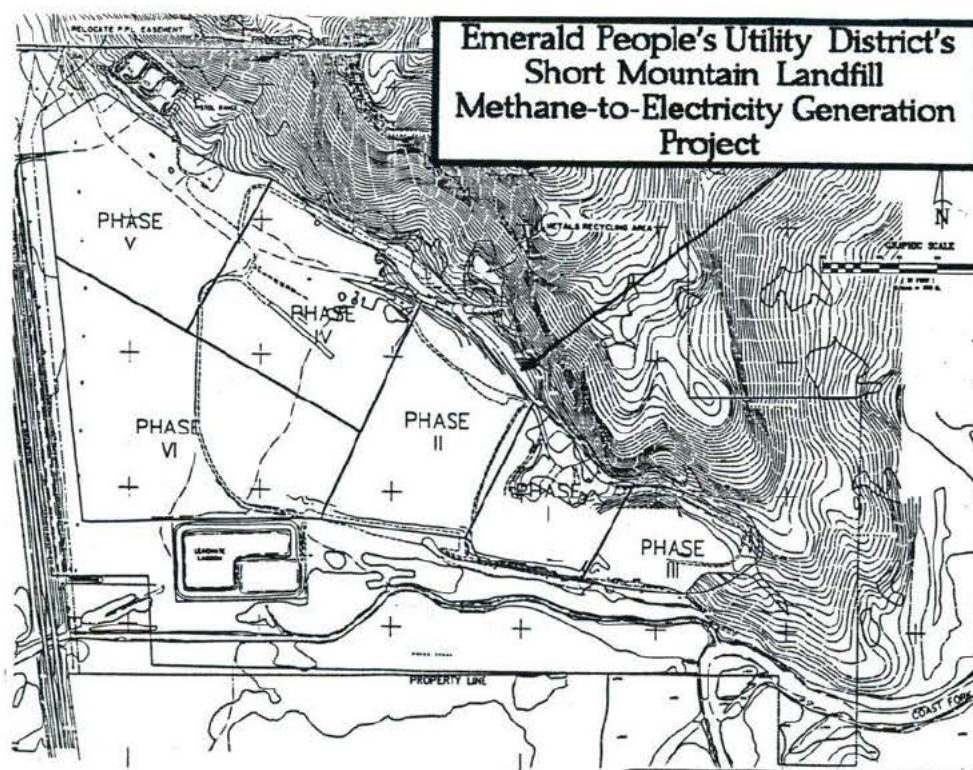
Alan Zelenka, resource specialist at the Emerald Public Utility District, selected the project's location after consultation with the landfill personnel and Mike Turner, manager Lane County's Waste Management Division.⁷⁷ Two sites for the electricity generation portion of the facility were originally considered by the utility. A location to the northwest of the proposed site was considered and rejected because of its distance from the Phase I and II fill areas. The cost involved in extending the landfill gas transport pipeline from the fill areas to the electricity generation site was the primary reason for rejecting the site.⁷⁸ Additionally, there was some question as to whether the landfill gas recovery system's compression and blower components would handle the load caused by the increased gas transport distance without an upgrade. Zelenka selected the second site for the reasons discussed below.

The electricity generation site is directly adjacent to the current landfill solid waste disposal area, allowing the landfill leachate and any LFG condensate

⁷⁷Alan Zelenka, "Personal Communication," Emerald People's Utility District, January 1990.

⁷⁸Ibid.

FIGURE 7: Short Mountain Landfill Fill Areas



Source: Russ Fetrow Engineering, Inc., Engineering Report for the Short Mountain Landfill, Lane County, May 1990, Sheet 2/21

collected by the landfill gas collection system to be easily returned to the landfill via the existing leachate collection ditches. The gas collection header pipeline from the grid of wells comprising the landfill gas collection system will be relatively short, lessening gas pressure loss during landfill gas transport from the well grid. The pipeline can be designed to fit through an existing drainage pipe under the landfill's road network.⁷⁹ The Emerald Public Utility District has a power line right-of-way and an existing transmission line paralleling the western border of the Short Mountain Landfill. The project's location will allow the power line connecting the electricity generation facility to the Emerald PUD's electricity grid to be short, lessening the need for costly power line construction and minimizing the environmental damage done by construction and line crews.⁸⁰

Clayey soils underlying the proposed project location will necessitate the construction of a gravel pad to support the heavy weight of the electricity generation and LFG collection equipment. The gravel pad will bring the elevation of the generating facility up to the level of the landfill's existing main roadway. Preliminary design work indicates that water drainage under the site will not be a problem, as Lane County has constructed drainage diversion ditches above the site and surrounding the landfill to prevent water drainage through the solid waste already in place.⁸¹

⁷⁹Ibid.

⁸⁰Ibid.

⁸¹Ibid.

CHAPTER IV

SITE DESIGN AND TECHNOLOGY ASSESSMENT

Landfill Gas Collection Systems

Any discussion of the site design and technology of a methane to electricity project should begin with the landfill gas collection system. Extreme care must be taken in the design and operational management of the LFG collection system to extract the maximum amount of LFG from the landfill, while maintaining gas pressures within the landfill and preventing air intrusion into the refuse.

Excessive air in the landfill can disrupt anaerobic conditions resulting in a decrease in gas production and quality. Air in the landfill may also result in rapid, uncontrolled oxidation in the waste; a process sometimes referred to as an underground landfill fire. Gas quality should be constantly monitored and the extraction rate carefully controlled when extracting gas from a landfill.⁸²

Landfill gas collection (extraction) systems may be categorized as either active or passive systems.⁸³ The type of collection system an individual landfill employs is entirely dependent on the end purpose of the gas recovery. Passive collection systems are employed to vent landfill gas to the atmosphere, thereby

⁸²Robert J. Pliska, Ronald J. Poland, and Kristin A. Alzheimer, Selection and Design of Landfill Gas Extraction Systems, Waste Management of North America, Inc., 1979, pp. 86-87.

⁸³USEPA, Air Emissions from Municipal Solid Waste Landfills - Background Information for Proposed Standards and Guidelines, Addendum, Draft EIS, March 1988, p. 4 - 1.

avoiding the lateral migration of LFG to areas surrounding the landfill and by inference, reducing the risk of a hazardous explosion of the gas.⁸⁴ Passive collection systems rely on the pressure differential between atmospheric pressure and internal landfill pressures to remove LFG from the landfill.⁸⁵ Landfill gas captured by means of a passive system is not amenable to recovery for energy generation and will not be discussed herein.

Active collection systems are employed to control the lateral migration and escape of landfill gas to the atmosphere, as well as for gas recovery and use in energy generation projects.⁸⁶ Active systems employ a mechanical blower or compressor to apply a vacuum to the landfill gas collection system, thus, improving the system's ability to extract landfill gas from the landfill, and insuring a steady flow of landfill gas for use in the internal combustion engines of an electricity generation project. Air compressors or blowers artificially create a pressure gradient differential (vacuum) between the landfill and the gas recovery system's wells and gas collection header pipe network to facilitate the withdrawal of the landfill gas from the landfill refuse.⁸⁷ Figure 8 shows the two major components of an active LFG collection system: 1- gas extraction wells or trenches, and 2- gas moving equipment (e.g., piping network and compressor).⁸⁸

⁸⁴Ibid.

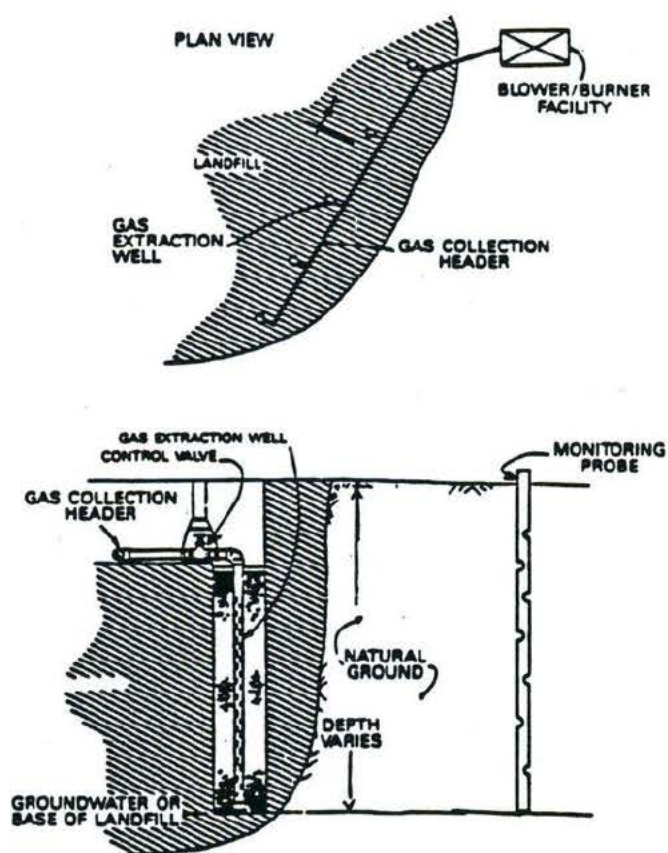
⁸⁵Robert J. Pliska, Ronald J. Poland, and Kristin A. Alzheimer, Selection and Design of Landfill Gas Extraction Systems, Waste Management of North America, Inc., 1979, p. 87.

⁸⁶USEPA, Air Emissions from Municipal Solid Waste Landfills - Background Information for Proposed Standards and Guidelines, Addendum, Draft EIS, March 1988, p. 4 - 1.

⁸⁷Ibid.

⁸⁸Ibid.

FIGURE 8: Active Landfill Gas Collection System



Source: USEPA, Air Emissions from Municipal Solid Waste Landfills - Background Information for Proposed Standards and Guidelines, Addendum, Draft EIS, March 1988, p. 4 - 2

Landfill Gas Extraction Wells

One of the initial steps in the construction of a landfill gas recovery system is the drilling and installation of LFG extraction wells. Collection of landfill gas is based on the premise that the landfill gas migrates through the path of least resistance, from its origin to the point at which it is expelled from the landfill. Extraction wells are used as permeable exit corridors for the landfill gas to follow as a path of least resistance as it migrates through the landfill.⁸⁹ The landfill gas recovery wells are an effective means to recover landfill methane for energy generation, and may, if the well grid and collection system are properly designed, provide an instrument for controlling lateral landfill gas migration from the surface and perimeter of the landfill.

Most landfill gas recovery systems use "vertical static vent wells" drilled into the landfill to create vertically oriented permeable corridors for landfill gas flow.⁹⁰ Static gas flow from an open well can be expected to increase as the vertical and lateral size of an extraction well increases. The landfill cover and perimeter soil must be relatively impermeable to the flow of landfill gas for these increases to occur.⁹¹

Gas extraction wells are generally drilled to the groundwater table at the landfill or near the base of a landfill's solid waste.⁹² The depth of a recovery well

⁸⁹EMCON Associates, State of the Art of Landfill Gas Recovery, prepared for Argonne National Laboratory, ANL/CNSV-TM-85, July 1981, p. 48.

⁹⁰Ibid., p.48.

⁹¹Ibid., p.48.

⁹²USEPA, Air Emissions from Municipal Solid Waste Landfills - Background Information for Proposed Standards and Guidelines, Draft EIS, March 1988, p. 4 - 3.

may be 50% to 100% of the refuse thickness, depending on the relative depth of the landfill.⁹³ Greater depth wells are found in shallow landfills where they are necessary to recover sufficient quantities of landfill gas. Shallow wells are generally found in deeper landfills, based on the assumption that most landfill gas will migrate (flow) upward. Thus, even relatively shallow wells should be able to recover a majority of the landfill gas from the lower refuse levels.⁹⁴

Penetration of the groundwater table by a landfill gas extraction well will draw groundwater into the wellbore, effectively sealing off the flow of landfill gas. The aforementioned technique of applying a compressor driven vacuum on the landfill gas recovery system to create a pressure differential gradient between the landfill and the recovery wells will only exacerbate the flow of water into the wellbore, thereby rendering the extraction well useless for the recovery of landfill gas.

Extraction wells are generally drilled with an excavated diameter of from 12 inches to 36 inches. A PVC plastic or cast iron pipe (well casing) of from 2 inches to 6 inches in diameter is then placed in the wellbore, the well is back-filled with crushed gravel around the pipe and the wellbore is sealed with bentonite or concrete around the top of the production casing to prevent air infiltration between the wellbore perimeter and the outside of the well casing.⁹⁵ Fiberglass and polyethylene well casing materials have also been used with a degree of success. Well casing size, material, and thickness should be selected on

⁹³EMCON Associates, State of the Art of Landfill Gas Recovery, prepared for Argonne National Laboratory, ANL/CNSV-TM-85, July 1981, p. 48.

⁹⁴Ibid., p. 50.

⁹⁵USEPA, Air Emissions from Municipal Solid Waste Landfills - Background Information for Proposed Standards and Guidelines, Draft EIS, March 1988, p. 4 - 3.

the basis of the expected landfill gas flow rate and the pressure loss within the well casing.⁹⁶

The production casing is perforated at the selected depth where landfill gas is to be collected, but the upper portion of the pipe is generally left solid to prevent air infiltration into the solid waste, thereby helping to preserve the anaerobic environment necessary for methanogenic bacteria to exist in the landfill. ⁹⁷ Oxygen is extremely toxic to methanogenic bacteria and may destroy the methane producing capability of the landfill. Refer to Chapter II for a complete discussion of this phenomenon.

Fifteen to eighty percent of the lower portion of the well casing may be perforated in shallow wells in deep landfills. "In a shallow landfill with excellent cover and perimeter gas containment, the well casing may be perforated over most of its length. Conversely, in a shallow landfill with poor gas containment, only the lower 25% or less may be perforated."⁹⁸ In both shallow and deep landfills, this percentage may vary according to refuse depth and landfill gas perimeter and surface containment conditions at the landfill.⁹⁹

Each well in the gas collection system is equipped with a butterfly valve to permit landfill gas flow rate control. This butterfly valve permits more flexibility in controlling overall LFG collection system operations and production. Landfill gas withdrawn from individual recovery wells is collected at a central location by means of a pipe network, generally referred to as a gas collection header.

⁹⁶EMCON Associates, State of the Art of Landfill Gas Recovery, prepared for Argonne National Laboratory, ANL/CNSV-TM-85, July 1981, p. 53.

⁹⁷Ibid., p. 49.

⁹⁸Ibid., p. 50.

⁹⁹Ibid., p. 50.

Individual wells are connected to the gas collection header above the butterfly valve, permitting individual wells to be shut in or throttled back if necessary. A compressor or blower unit, if used in the landfill gas recovery process, is connected to the system at the gas collection header.¹⁰⁰ Figure 9 illustrates the design and structural layout of a typical vertically oriented landfill gas extraction well.

Recovery Well Field Design

The recovery well grid design, the setback distances from the landfill perimeter and the inter-well spacing of the gas extraction wells are dependent on a number of site specific landfill characteristics. Well spacing may be affected by the type of waste, the degree of waste compaction, the depth of the landfill, the moisture content of the gas, and the landfill gas generation rate.¹⁰¹ The magnitude of the pressure gradient differential (vacuum) applied by the compressors in a landfill gas recovery system also may affect the final inter-well spacing and design of the LFG collection system.¹⁰² Setback distances from the landfill perimeter are primarily controlled by the nature of the surface cover and the soil permeability surrounding the outer perimeter.

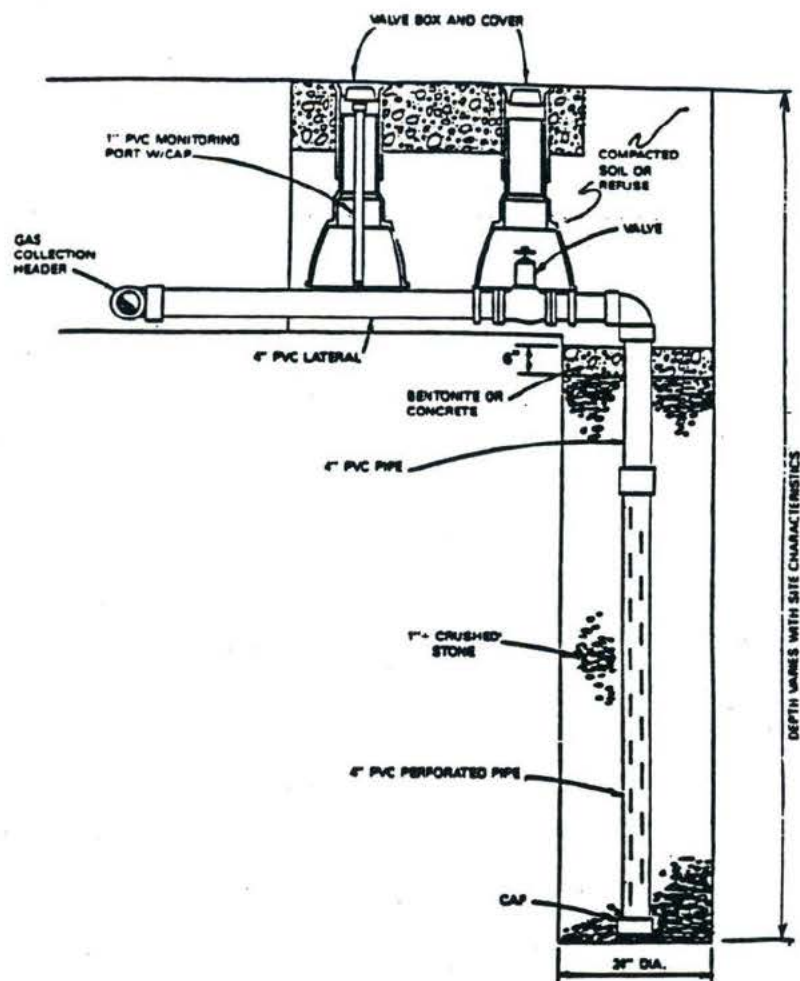
The effectiveness of an active landfill gas collection system is dependent on careful design and operation of the system. According to the United States Environmental Protection Agency, an effective LFG collection system should be

¹⁰⁰Ibid., p. 52.

¹⁰¹USEPA, Air Emissions from Municipal Solid Waste Landfills - Background Information for Proposed Standards and Guidelines, Draft EIS, March 1988, p. 4 - 7.

¹⁰²Ibid., p. 4 - 3.

FIGURE 9: Typical Landfill Gas Extraction Well



Source: USEPA, Air Emissions from Municipal Solid Waste Landfills - Background Information for Proposed Standards and Guidelines, Draft EIS, March 1988, p. 4 - 4

able to collect from 40 % to 60 % of the landfill gas generated within a landfill.¹⁰³

The system should be designed to include the following attributes:

- 1- Gas moving equipment capable of handling the maximum landfill gas generation rate.
- 2- Collection wells configured such that landfill gas is effectively collected from all areas of the landfill.
- 3- Design provisions for monitoring and adjusting the operation of individual extraction wells.¹⁰⁴

Compressors and blowers need to be sized to handle the maximum expected landfill gas generation rate. The collection system's header pipes need to be sized and the grid designed to minimize any pressure drop during landfill gas collection and transport.¹⁰⁵

Each well in the gas collection system has what is known as a "zone or radius of influence."¹⁰⁶ The zone of influence of a landfill gas recovery well is assumed to define a distance from the well center to the point at which the pressure gradient applied by the system's compressor or blower approaches zero.¹⁰⁷ This definition is based on the assumption that no landfill gas can be drawn to recovery well from a distance greater than the well's zone of influence.

Within this context, the radius of influence is a fictitious concept in that not all gas within the radius of influence can be captured (i.e., some gas will escape to the atmosphere) and some

¹⁰³Ibid., p. 4 - 6.

¹⁰⁴Ibid., p. 4 - 6.

¹⁰⁵Ibid., p. 4 - 6.

¹⁰⁶EMCON Associates, State of the Art of Landfill Gas Recovery, prepared for Argonne National Laboratory, ANL/CNSV-TM-85, July 1981, p. 56.

¹⁰⁷USEPA, Air Emissions from Municipal Solid Waste Landfills - Background Information for Proposed Standards and Guidelines, Draft EIS, March 1988, p. 4 - 7.

gas will be drawn to the well from a distance greater than the radius of influence. However, the errors inherent in these two simplifications tend to cancel one another, and reasonable flow-rate estimates are usually achieved. The concept of radius of influence is a convenient and useful one in establishing inter-well spacing and in estimating potential well flow rates.¹⁰⁸

In designing the well field grid for a landfill gas collection system some degree of overlap of the zone of influence for wells near the landfill perimeter is desirable, especially in a system designed to include control of landfill gas migration. The design may have some latitude in well spacing at the perimeter, primarily because the gas extraction rate and the zone of influence are interdependent. Individual wells with butterfly (throttle) valves may have their flow rates adjusted after the system is in place to provide more effective migration control and efficient landfill gas recovery.¹⁰⁹

Efficient recovery of landfill gas requires a well placement design that maximizes landfill gas extraction. The best design for maximizing landfill gas recovery uses a pattern of wells located at the vertices of equilateral triangles. The sides of the triangles should be equal to the predetermined inter-well spacing for the landfill gas recovery system.¹¹⁰ Figure 10 shows the optimal design for inter-well spacing in an effective gas collection system. Constraints caused by the physical geometry of the landfill may preclude the possibility of an entire collection system designed around these parameters. Smaller inter-well spacing at the perimeter of the landfill also may disrupt the desired equilateral

¹⁰⁸EMCON Associates, State of the Art of Landfill Gas Recovery, prepared for Argonne National Laboratory, ANL/CNSV-TM-85, July 1981, p. 56.

¹⁰⁹Ibid., p. 58.

¹¹⁰Ibid., p. 58.

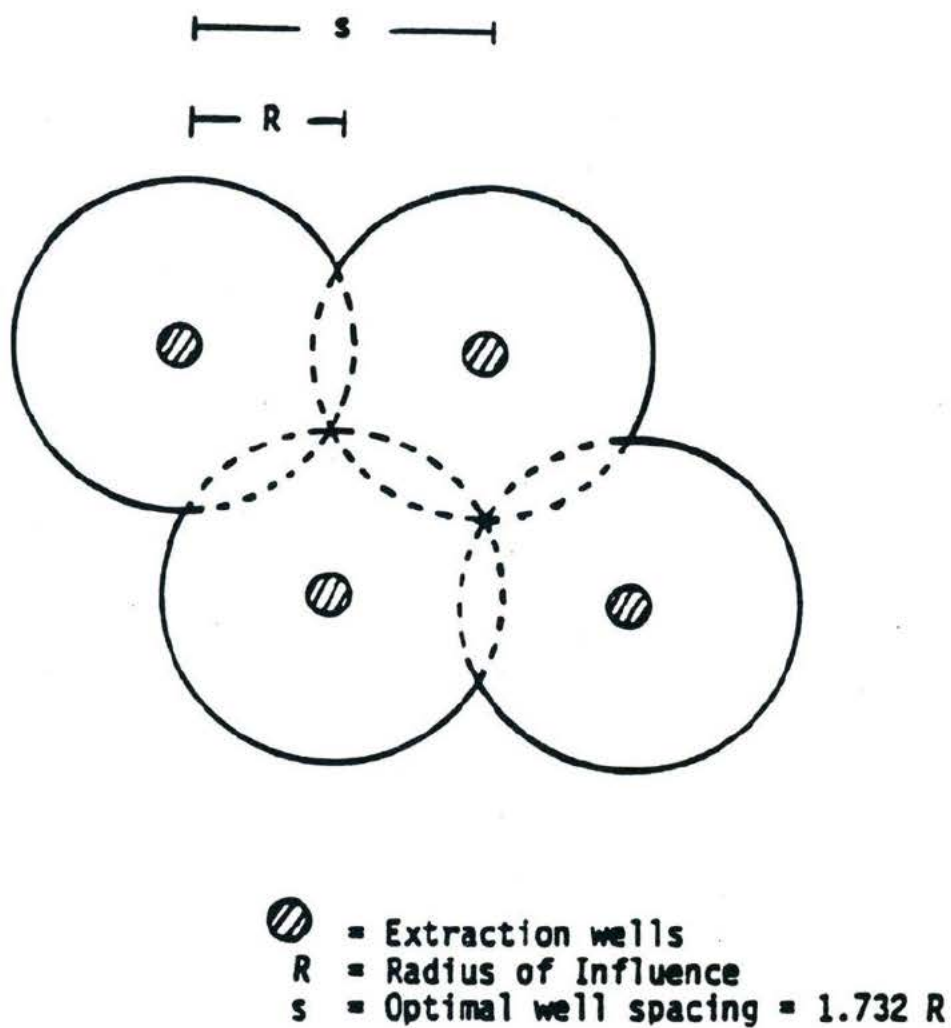
triangle pattern of wells. Perimeter wells are generally designed to operate at lower landfill gas extraction flow rates and have closer inter-well spacing to limit air infiltration into the refuse. Landfill gas recovery wells located away from the landfill's perimeter generally are less susceptible to air infiltration and usually exhibit greater inter-well spacing and higher landfill gas extraction flow rates. One design technique that may enhance landfill gas recovery at deeper landfills, employs alternating deep wells using high vacuum draws with shallow wells using lower landfill gas extraction vacuum draws. A landfill gas collection system designed in this manner would allow greater system stressing with increased levels of landfill gas extraction at lower landfill levels, while still limiting air infiltration into the landfill refuse.¹¹¹

Electricity Generation From Landfill Gas

Presently, there are three main types of landfill gas to electricity generation systems employed in the United States. Gas-fired boiler to steam turbine systems, gas turbine systems, and internal combustion engine driven systems are in use at landfill gas to electricity generation projects across the country. These technologies are matched to an individual landfill according to the quantity and quality of the landfill gas produced there. Gas turbine systems and internal combustion engine systems are the most widely used technologies. All three technologies will likely qualify as BACT (Best Available Control Technology) for the destruction of methane and VOC (volatile organic compounds) under the tough new landfill gas migration regulations (Subtitle D of the Resource

¹¹¹Ibid., p. 58.

FIGURE 10: Effective Inter-well Spacing and Design



Source: USEPA, Air Emissions from Municipal Solid Waste Landfills - Background Information for Proposed Standards and Guidelines, Draft EIS, March 1988, p. 4 - 8

Conservation and Recovery Act) to be issued by the Environmental Protection Agency sometime in 1991.¹¹²

Gas-fired Boiler to Steam Turbine Technology

Gas-fired boiler to steam turbine systems are the most expensive technological option available for landfill gas to electricity generation projects.¹¹³ According to Environmental Protection Agency (EPA) figures, a 47 megawatt electricity generation facility using this technology would cost in excess of \$33 million dollars.¹¹⁴ Conversely, the gas-fired boiler to steam turbine system is the cleanest burning technology, may use lower quality (methane content) landfill gas, and has the most positive environmental impact on air quality at landfill sites.¹¹⁵ The EPA figures indicate that gas-fired boiler to steam turbine technology may use landfill gas with a minimum content of 12% methane, compared to the gas turbine technology that needs higher quality landfill gas with a minimum content of 35% methane.¹¹⁶ Figure 11 shows the positive and negative impacts on air emissions at landfills using a gas-fired boiler to steam turbine electricity generation system.

Gas-fired boiler to steam turbine technology utilizes a gas-fired steam boiler that produces high pressure steam, a steam driven turbine or turbines, and

¹¹²Greg Maxwell, "Will Gas-to-Energy work at Your Landfill?," Solid Waste & Power, June 1990, p. 50.

¹¹³USEPA, Air Emissions from Municipal Solid Waste Landfills - Background Information for Proposed Standards and Guidelines, Draft EIS, March 1988, p. A - 12.

¹¹⁴*Ibid.*, p. A - 12.

¹¹⁵*Ibid.*, p. A - 6.

¹¹⁶*Ibid.*, p. A - 20.

an electricity generating system. Steam produced in the boiler is passed through superheaters before being fed to the steam turbines. The steam from the superheaters propels turbine blades, which are in turn connected to electricity generation equipment. Excess gas and gas-byproducts are flared through a series of system stack flares.¹¹⁷

Primarily due to the higher capital cost and operational budget considerations, this type of electricity generation system would typically have to be employed at a large capacity, deeper landfill with a relatively high projection of methane generation and recovery. The Waste Management Company of North America, largest operator of landfill gas to electricity generation projects in this country, does not employ this technology in any of the 20 projects that it manages.¹¹⁸

Gas Turbine Technology

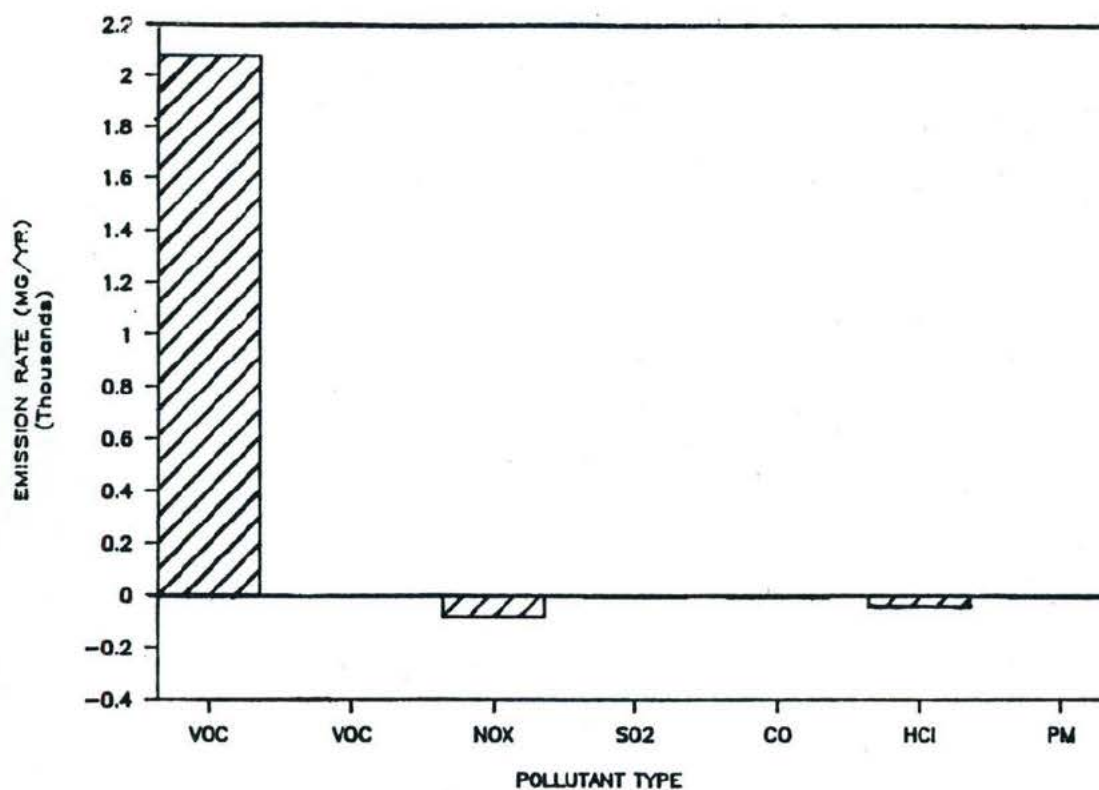
Gas turbine technology is moderately less expensive than the gas-fired boiler to steam turbine technology, but retains much of the same positive impact on ambient air quality as the latter system. Figure 12 shows the positive and negative effects of the gas turbine technology on landfill ambient air quality. As previously stated, gas turbines do require higher quality landfill gas with at least a 35% methane content.¹¹⁹ The same economies of scale do apply, however, to both technologies.

¹¹⁷Ibid., p. A - 8.

¹¹⁸Greg Maxwell, "Will Gas-to-Energy work at Your Landfill?," Solid Waste & Power, June 1990, p. 44.

¹¹⁹USEPA, Air Emissions from Municipal Solid Waste Landfills - Background Information for Proposed Standards and Guidelines, Draft EIS, March 1988, p. A - 20.

FIGURE 11: Gas-fired to Steam Turbine Air Quality Impacts



Note: The positive value of the emission rate is the amount removed and the negative value is the amount emitted.

Source: USEPA, Air Emissions from Municipal Solid Waste Landfills - Background Information for Proposed Standards and Guidelines, Draft EIS, March 1988, p. A - 6

The Waste Management Company of North America uses gas-fired combustion turbine technology only at the larger capacity landfills under its operational management. The technology is used primarily at landfills that generate more than 2 million cubic feet of landfill gas per day¹²⁰. Eleven of the twenty landfill gas recovery operations run by the company employ combustion turbines to generate electricity.¹²¹

Prior to combustion in the turbine's combustion chamber, the landfill gas is dehydrated (condensate removed) and compressed to 70 -90 psig. Only then, is it directly fed into the combustion chamber of the gas turbine. The turbine in turn propels the electricity generators. Condensate (water) removed from the landfill gas is either stored for off-site treatment and disposal or returned to the landfill leachate collection system for treatment and disposal. Excess landfill gas and non-methane compounds separated from the landfill gas when condensate is removed are diverted from the fuel stream and flared through a network of stack flares. "Relatively heavy maintenance is required for the gas turbine system, especially the compressor."¹²² Dust, mud, and other contaminants collected by the landfill gas recovery system contaminates the oil in the compressor or blower system. Monthly and even bimonthly oil changes in the compressor system may be required to keep the landfill gas recovery and combustion operation running smoothly.¹²³

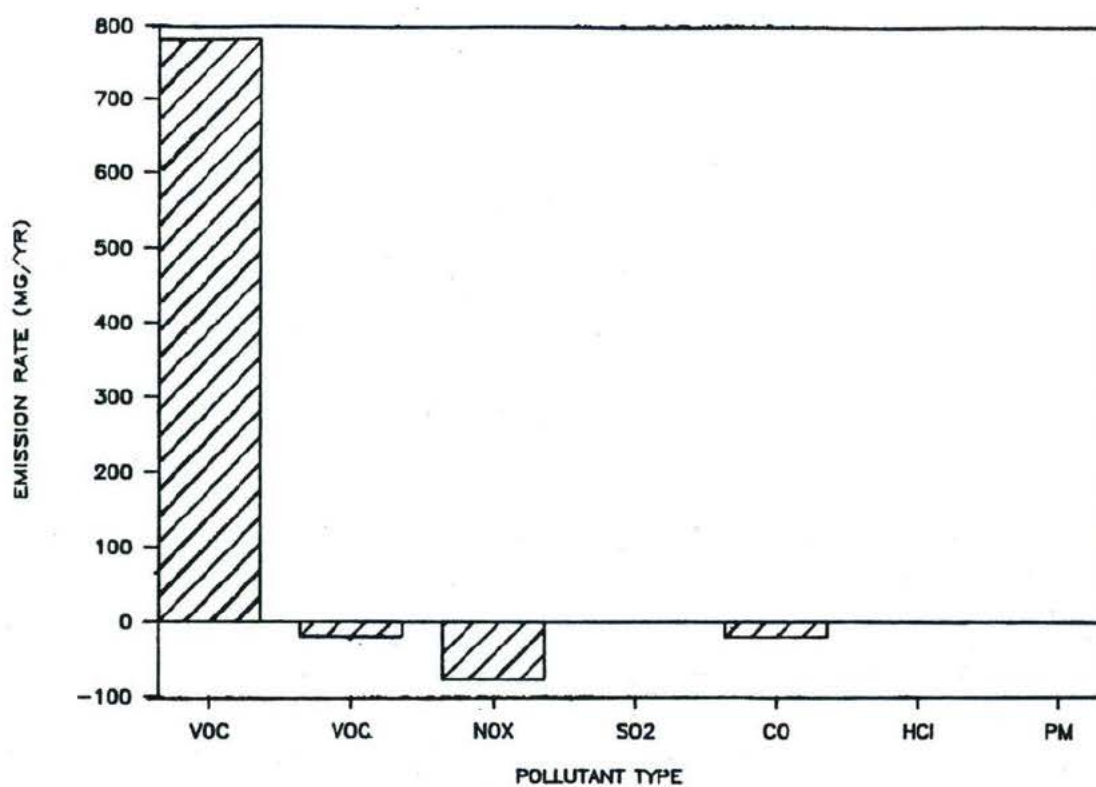
¹²⁰Greg Maxwell, "Will Gas-to-Energy work at Your Landfill?," Solid Waste & Power, June 1990, p. 45.

¹²¹*Ibid.*, p. 44.

¹²²USEPA, Air Emissions from Municipal Solid Waste Landfills - Background Information for Proposed Standards and Guidelines, Draft EIS, March 1988, p. A - 20.

¹²³*Ibid.*, p. A - 20.

FIGURE 12: Gas Turbine Positive and Negative Air Quality Effects



Note: The positive value of the emission rate is the amount removed and the negative value is the amount emitted.

Source: USEPA, Air Emissions from Municipal Solid Waste Landfills - Background Information for Proposed Standards and Guidelines, Draft EIS, March 1988, p. A - 17

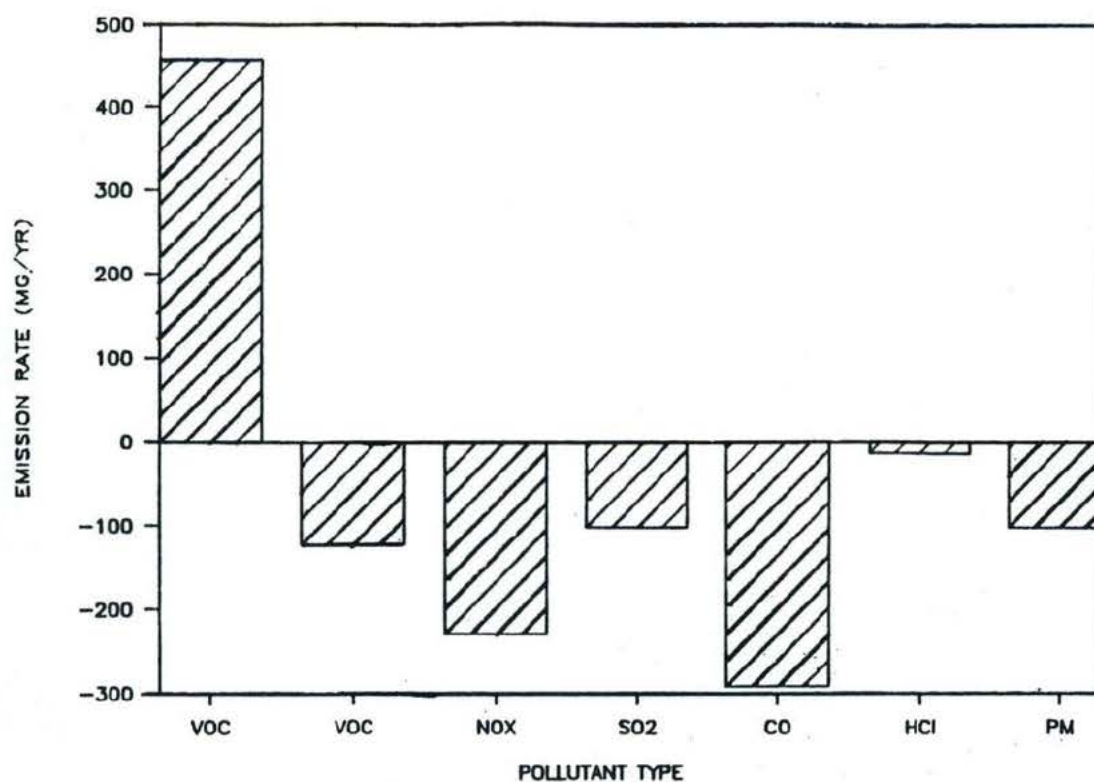
Internal Combustion Engine Technology

The internal combustion engine technology is the least expensive of the three technological options available to landfill gas to electricity generation operations. From the perspective of positive and negative effects on landfill ambient air quality, the internal combustion engine technology also is the dirtiest technological option that may be employed. While the overall ratio of volatile organic compounds (VOC) removed to volatile organic compounds (VOC) emitted is positive, the technology produces much greater quantities of nitrogen oxide (NO_x), sulfur dioxide (SO_2), carbon monoxide (CO), hydrocarbons, (HC) and particulate matter (PM) than does the other two available technological options.¹²⁴ Figure 13 shows the positive and negative effects of this technology on air pollutants and ambient air quality.

The internal combustion engine technology employs much the same types of landfill gas processing prior to combustion as does the gas turbine technology. Landfill gas condensate is removed from the gas stream via condensate traps and dehydrators, prior to gas compression by the blowers or compressors. The water is either stored for treatment and disposal at a remote site or returned to the landfill leachate collection system. The compressed and dehydrated gas stream then enters the large internal combustion engines for use as a fuel. Each engine is in turn connected to electricity generators. Gas stack flares may be used as a means of disposing of excess gas coming through the system or for gas flaring during emergency or normal operational shutdowns.

¹²⁴Ibid., p. A - 24, 25.

FIGURE 13: Internal Combustion Positive and Negative Air Quality Effects



Note: The positive value of the emission rate is the amount removed and the negative value is the amount emitted.

Source: USEPA, Air Emissions from Municipal Solid Waste Landfills - Background Information for Proposed Standards and Guidelines, Draft EIS, March 1988, p. A - 17

Engines employed in landfill operations generally are of the low NO_x emission ("clean burn") variety.¹²⁵ Low NO_x emission engines use a very lean fuel mixture to reduce air pollutant emissions of this type. In other words, the ratio of air to methane in the fuel mixture is adjusted upward to allow cleaner and more complete combustion of the fuel.¹²⁶ Low NO_x emission technology is now recognized as BACT (Best Available Control Technology) by the USEPA for the purpose of complying with PSD (Prevention of Significant Air Quality Deterioration) emission standards for new sources under the Clean Air Act.¹²⁷ These emission standards and the BACT concept will be addressed more fully in the next chapter.

Short Mountain Landfill Methane to Electricity Project

The EMCON Associates of San Jose, California performed the original design work on the landfill gas recovery system for the Emerald People's Utility District's Short Mountain Landfill Methane to Electricity Project.¹²⁸ Delays in the project's anticipated start up date will necessitate a partial reworking of the gas recovery well field design, but much of the design will remain as presented herein. While waiting for Emerald PUD to begin work on the landfill gas recovery system portion of its electricity generation project, the Lane County Solid Waste Division proceeded with plans to commence solid waste filling over

¹²⁵Ibid., p. A - 26.

¹²⁶Curt E. Chadwick, Application of Caterpillar Spark-Ignited Engines for Landfill Gas, Caterpillar Engine Division, Oak Brook, Illinois, 1988, p. 1.

¹²⁷USEPA, "Top-Down" Best Available Control Technology Guidance Document, Office of Air Quality Planning and Standards, Durham, North Carolina, March 15, 1990, p. 1.

¹²⁸EMCON Associates, Short Mountain Landfill Gas Recovery System, Drawings for Emerald People's Utility District, March 1990, cover sheet.

a previously completed portion of the landfill area, forcing the requisite design changes.¹²⁹ The EMCON Associates is now proceeding with the necessary design modifications to its original landfill gas recovery system plan for the Short Mountain Landfill.¹³⁰

Short Mountain Landfill Gas Recovery System

The Emerald PUD's landfill gas recovery system at the Short Mountain Landfill was designed to fit within the existing landfill geometry and fill area parameters. Two areas will be covered by the landfill gas recovery system. Figure 14 shows the two active fill areas and the LFG recovery system design plan for each. Landfill Area A covers the smaller (total surface area) portion of the easterly segment of the Short Mountain Landfill, where solid waste filling was recently completed to a depth of approximately 90 feet. The well placement in Area A will employ 150 feet well-spacing.¹³¹ Landfill Area B lies directly to the west of Landfill Area A, and is currently, the active fill area at the Short Mountain Landfill. EMCON's original design for the landfill gas recovery system at Short Mountain anticipated completion of the collection system prior to renewed solid waste deposition in Landfill Area B, necessitating certain design changes to integrate this recent development into the plan. The original fill at Landfill Area B covers a much larger surface area than does Landfill Area A, but the refuse was only deposited to an average depth of approximately 40 feet. The

¹²⁹Alan Zelenka, "Personal Communication," Resource Specialist - Emerald People's Utility District, Eugene, Oregon, January 11, 1990.

¹³⁰Ibid.

¹³¹EMCON Associates, Short Mountain Landfill Gas Recovery System, Drawings for Emerald People's Utility District, March 1990, Drawing No. 1.

well placement in Area B will employ 200 feet well-spacing.¹³² Figure 14 reflects the original landfill gas recovery design plan without regard to EMCON's future design changes.

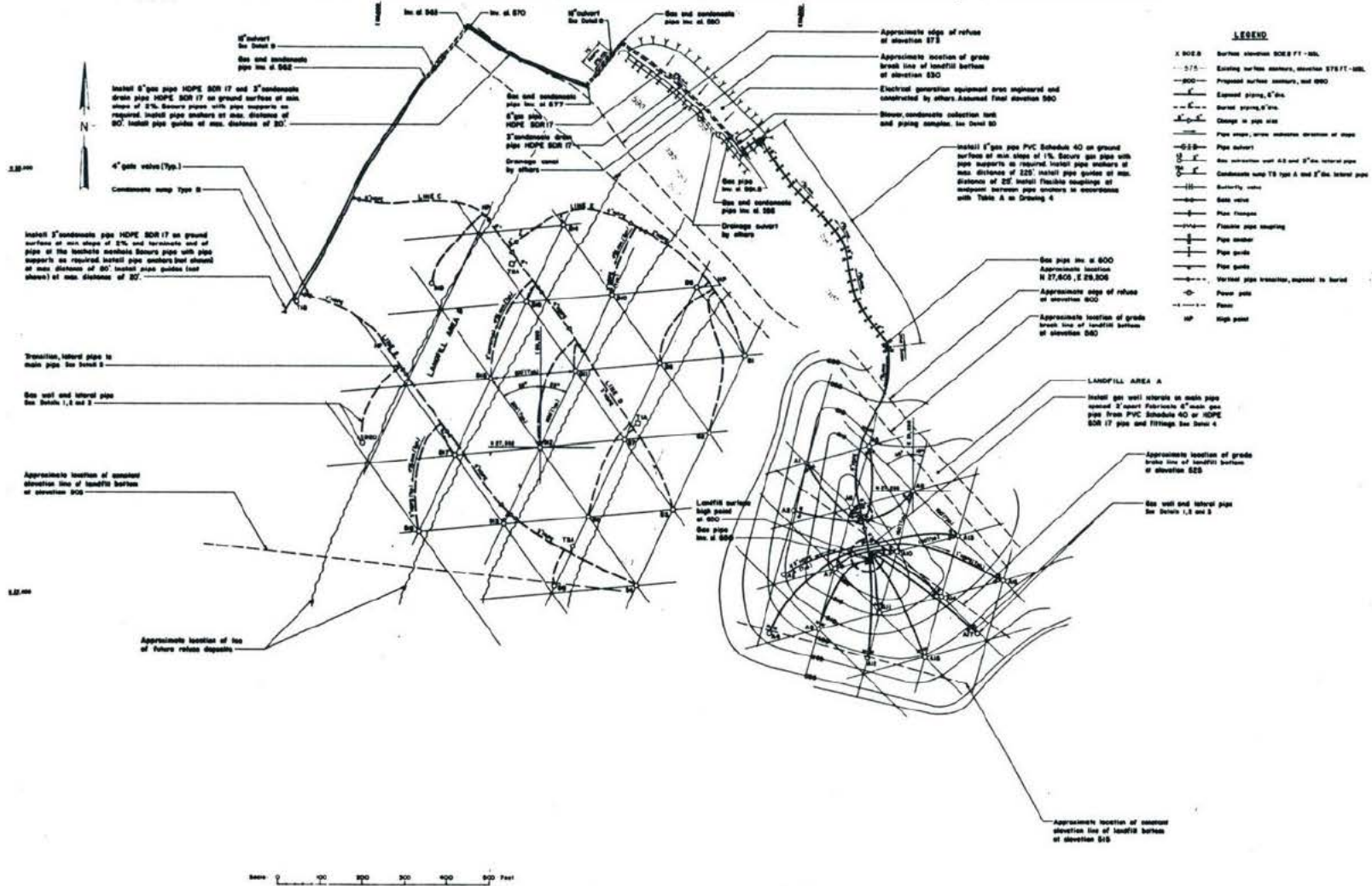
As is evident from Figure 14, the landfill gas recovery well field plan incorporates the gas recovery enhancing, equilateral triangle design for landfill gas recovery well placement. Deviations from the recovery enhancement design scheme are planned where they are dictated by the existing landfill geometry. This design plan will optimize the landfill gas recovery flow rates for the Emerald PUD's electricity generation project, while limiting air infiltration into the perimeter of the landfill. Table 8 delineates the individual well placement parameters for Landfill Area A. Table 9 shows the individual well placement parameters for Landfill Area B. Individual well depth and spacing varies according to the depth of the refuse and the surface area included in the coverage.

The gas collection header system at the Short Mountain facility is designed to handle the maximum landfill gas flow rates (volumes) and LFG pressures that are anticipated over the life of the electricity generation project. Individual header pipe materials include both PVC Schedule 40 and HDPE SDR 17 (high density polyethylene) plastics as required by the system design plan. The gas collection header pipe sizes range from 3 inches to 8 inches, depending on the pipe's location in the system and the expected landfill gas volumes and pressures to be handled by the system.¹³³

¹³²Ibid.

¹³³Ibid.

FIGURE 14: Short Mountain Landfill Gas Recovery Areas A and B



Source: EMCON Associates, Short Mountain Landfill Gas Recovery System, Drawings for Emerald People's Utility District, March 1990, Drawing No. 1

TABLE 8: Area A Landfill Gas Well Data

Landfill Gas Well Data A-Wells Spaced 150 Apart				
Gas Well	Approximate Landfill Surface Elevation (ft)	Approximate Landfill Bottom Elevation (ft)	Approximate Depth of Refuse (ft)	Gas Well Total Depth (ft)
A-1*	610	526	84	74
A-2*	610	524	86	76
A-3*	610	519	91	81
A-4*	602	515	87	77
A-5	611	551	60	50
A-6	621	530	91	81
A-7	620	521	99	89
A-8*	607	517	90	80
A-9	609	552	57	47
A-10	620	525	95	85
A-11	615	519	96	86
A-12*	604	515	89	79
A-13	607	552	55	45
A-14	613	525	88	78
A-15*	605	517	88	78
A-16	606	552	54	44
A-17*	600	523	77	67

Note: * Exterior Wells

Source: EMCON Associates, Short Mountain Landfill Gas Recovery System,
Drawings for Emerald People's Utility District, March 1990, Drawing No.
2

TABLE 9: Area B Landfill Gas Well Data

Landfill Gas Well Data B-Wells Spaced 200 Apart				
Gas Well	Approximate Landfill Surface Elevation (ft)	Approximate Landfill Bottom Elevation (ft)	Approximate Depth of Refuse (ft)	Gas Well Total Depth (ft)
B-1	568	526	42	37
B-2	559	521	38	33
B-3	554	515	39	34
B-4	548	508	40	35
B-5	570	528	42	37
B-6	559	523	36	31
B-7	557	519	38	33
B-8	553	513	40	35
B-9	549	507	47	42
B-10	564	525	39	34
B-11	560	521	39	34
B-12	558	516	42	37
B-13	550	511	39	34
B-14	563	527	36	31
B-15	560	522	38	33
B-16	554	519	35	30
B-17	554	514	40	35
B-18	552	509	43	38
B-19	560	521	39	34
B-20	558	513	43	38

Source: EMCON Associates, Short Mountain Landfill Gas Recovery System,
 Drawings for Emerald People's Utility District, March 1990, Drawing No.
 2

Short Mountain Landfill Combustion Technology

The Emerald People's Utility District selected the internal combustion engine technology to power its electricity generation facility at the Short Mountain Landfill, Lane County, Oregon, after studying the other available alternatives for landfill gas combustion. The gas turbine and the gas-fired boiler to steam technologies were evaluated and rejected early in the Emerald PUD's planning process. After preliminary analysis of both technologies by the utility's resource planning staff, the two technology options were judged to be unacceptable from an economic standpoint. The initial high capital expenditures and the continuing higher operational costs of the two technology options, projected low landfill gas extraction volumes at the Short Mountain Landfill, and the low avoided cost of electricity generation in the Pacific Northwest, combined to eliminate both technologies from further consideration by the utility.¹³⁴ Simply put; the project would not be built if either of these technologies were employed.

According to the landfill gas recovery feasibility study performed by EMCON Associates in July 1987, the Emerald PUD can expect to recover approximately 1.0 - 1.7 million cfd (cubic feet per day) of landfill gas from the Short Mountain Landfill during the utility's immediate planning period, 1988 - 1998.¹³⁵ Under normal operating conditions, 700,000 cfd (cubic feet per day) of landfill gas is sufficient to generate 1 megawatt (1000 kilowatts) of continuous

¹³⁴Alan Zelenka, "Personal Communication," Resource Specialist - Emerald People's Utility District, Eugene, Oregon, January 1990.

¹³⁵EMCON Associates, Landfill Gas Recovery Feasibility Study, Short Mountain Landfill, Lane County, Oregon, prepared for Emerald People's Utility District, July 1987, p. 8.

electric power.¹³⁶ This translates to approximately 2.1 megawatts of initial electricity generating potential at the Short Mountain Landfill. Landfill gas recovery volume is expected to peak in the years 2006 - 2007, at a recovery rate of over 2.7 million cfd.¹³⁷ The relatively small volume of the expected landfill gas deliverability at the landfill and the utility's low avoided cost of purchasing electric power from the Bonneville Power Administration were the two primary criteria leading to the Emerald PUD's decision to proceed with a project employing internal combustion engine technology to burn the recovered landfill gas.

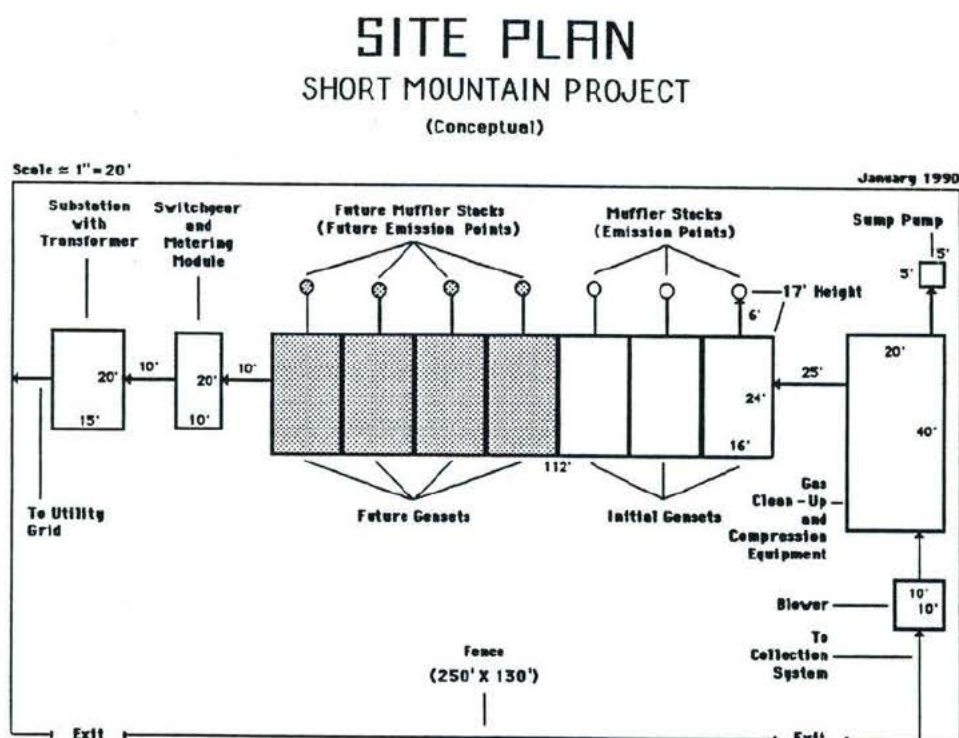
Initially, three 900 horsepower low emission internal combustion engines will power the 2.1 megawatt electricity generation facility at the Short Mountain Landfill. As landfill gas extraction and flow rates increase over the next 15 years, four additional 900 horsepower low emission internal combustion engines will be added to the project for a total of 7 low emission internal combustion electricity gensets. The additional generators will boost the project's electricity generating capacity to nearly 5 megawatts by the year 2006.¹³⁸ Figure 15 shows the anticipated electricity generation site plan for the Short Mountain project.

¹³⁶Ibid.

¹³⁷Emerald People's Utility District, Short Mountain Landfill Gas Utilization Analysis, January 24, 1990, p. 2.

¹³⁸Ibid.

FIGURE 15: Short Mountain Landfill Electricity Generation Installation



Source: Emerald People's Utility District, Short Mountain Landfill Methane-to-Electricity Project Air Contaminant Discharge Permit Application for Lane Regional Air Pollution Authority, February 14, 1990, p. 12

CHAPTER V

AIR POLLUTION CONTROL

Air Pollution Control Authority and Standards

The Lane Regional Air Pollution Authority (LRAPA) is the only local air pollution control agency in the state of Oregon, having been in existence since 1968. Similar local air pollution control agencies once existed in Salem, Oregon and Portland, Oregon, but are no longer in operation. The air pollution control agency is responsible for developing and administering a local program of air pollution control in Lane County, Oregon.¹³⁹

The Lane Regional Air Pollution Authority's main office is located in Springfield, Oregon. The agency maintains several air quality monitoring sites that are located throughout Lane County. The agency's funding comes from a variety of sources; including local government contributions, state and federal grants, supplemental grants for special projects, permit fees, and other miscellaneous contracts.¹⁴⁰

LRAPA'S purpose is to conduct an air quality control program that reflects local priorities and, at the same time, meets minimum federal and state criteria for air pollution control.¹⁴¹

¹³⁹Lane Regional Air Pollution Authority, 1988-1990 Air Quality Report, Springfield, Oregon, 1990, p. 16.

¹⁴⁰Ibid.

¹⁴¹Ibid.

The Oregon Department of Environmental Quality (DEQ), through its Air Quality Division, is responsible for air pollution control program development and the issuance of air pollution control permits in the remainder of the state of Oregon.¹⁴² The Department of Environmental Quality submits proposed regulations or revisions to existing regulations to the Oregon Environmental Quality Commission for approval. The regulations and any revisions thereof, as promulgated by the Department of Environmental Quality, carry the force of law after Commission approval.¹⁴³

The Lane Regional Air Pollution Authority follows the same procedure for promulgating and revising regulations as the Oregon DEQ. Its regulations also carry the force of law after approval by the Oregon Environmental Quality Commission. The regulations of both agencies must meet the guidelines established in the State Implementation Plan and the Clean Air Act, as codified in 42 U.S.C.A. §§ 7401-7462.

Again in this chapter, the Emerald People's Utility District's Short Mountain Landfill Methane-to-Electricity Project will be used as a case study to illustrate the process of meeting the air pollution control standards for new sources of air pollution and obtaining the air contaminant discharge permit required of such projects. The Lane Regional Air Pollution Authority is responsible for the issuance of the air contaminant discharge permit for the Emerald PUD's project because the project site lies entirely within the boundaries of Lane County, Oregon.

¹⁴²Department of Environmental Quality - Air Quality Control Division, 1989 Oregon Air Quality Annual Report, Portland, Oregon, 1990, p. 17.

¹⁴³Ibid.

Operating Guidelines

The Department of Environmental Quality and the Lane Regional Air Pollution Authority operate under the guidelines established by the State of Oregon Clean Air Act Implementation Plan (SIP) for meeting the national primary and secondary ambient air quality standards (NAAQS). The national requirement for states to promulgate state implementation plans dealing with air quality and air pollution control was passed by Congress in the Clean Air Act (CAA § 110). Oregon's state implementation plan was submitted to the EPA on January 25, 1972, and was approved by the administrator of the Environmental Protection Agency, with certain exceptions, in 1973.¹⁴⁴ The SIP has been revised on numerous occasions since 1972, all with the approval of the administrator of the United States Environmental Protection Agency.¹⁴⁵ The state implementation plan must be approved by the administrator of the United States Environmental Protection Agency or the agency will promulgate and implement a federal plan of its own for the state (Clean Air Act § 110).

State implementation plans must adopt air pollution control strategies for the attainment and maintenance of the national ambient air quality standards. According to regulations adopted by the Environmental Protection Agency, state implementation plans must include a program to prevent significant deterioration of ambient air quality (PSD) in areas that have achieved attainment status of the national air quality standards. The prevention of significant deterioration of ambient air quality of attainment areas within the state is to be

¹⁴⁴40 C.F.R. § 52.1970.

¹⁴⁵40 C.F.R. § 52.1970.

accomplished by "emission limitations and other measures as may be necessary."¹⁴⁶ State air quality standards may be stricter than the federal standards, but must meet the minimum levels of air quality as stated in the national ambient air quality standards.

The requirement of the United States Environmental Protection Agency to promulgate national primary and secondary ambient air quality standards for each pollutant that the agency has issued air quality criterion for was adopted by Congress in § 109 of the Clean Air Act. The primary national ambient air quality standards are intended to protect the public health [CAA § 109 (b)(1)]. The more stringent secondary national ambient air quality standards are designed to protect the public welfare [CAA § 109 (b)(2)].

Oregon's state implementation plan calls for air pollution control strategies that will achieve the more stringent secondary ambient air quality standards.¹⁴⁷ The plan includes strategies to prevent significant deterioration of air quality in "clean-air" areas and to bring those areas that are listed as nonattainment for one or more pollutants into compliance with the standards. National wilderness areas and the Crater Lake National Park in Oregon are classified as Class I attainment areas.¹⁴⁸ Class I areas maintain the cleanest air and the strictest prevention of significant deterioration of air quality measures. All other attainment areas in the state are classified as Class II for purposes of the prevention of significant deterioration of air quality measures.¹⁴⁹ Table 10

¹⁴⁶40 C.F.R. § 51.166 (a) (1).

¹⁴⁷Department of Environmental Quality - Air Quality Control Division, 1989 Oregon Air Quality Annual Report, Portland, Oregon, 1990, p. 19.

¹⁴⁸O.R.S. § 340-31-120.

¹⁴⁹O.R.S. § 340-31-130 (1) (a).

TABLE 10: Lane Regional Air Pollution Authority Ambient Air Standards

Ambient Air Standards	
Concentrations shall not exceed:	
<u>Particle Fallout Rate</u>	1- 3.5 grams per square meter per month with a calcium oxide concentration of 0.35 per square meter per month.
<u>Suspended Particulate Matter</u>	1- 60 micrograms per cubic meter (μ/m^3) of total suspended particulate - annual geometric mean for calendar year. 2- 150 μ/m^3 of total suspended particulate - 24 hour average concentration once per year. 3- 50 μ/m^3 PM_{10} as an annual arithmetic mean. 4- 150 μ/m^3 PM_{10} as 24 hour concentration. 5- 20 μ/m^3 concentrations of calcium oxide as total suspended particulate.
<u>Odors</u>	1- No emission of odorous matter that may cause a public nuisance.
<u>Sulfur Dioxide</u>	1- 0.02 Parts per million (ppm) annual arithmetic mean for calendar year. 2- 0.10 ppm - 24 hour average concentration more than once per year. 3- 0.50 ppm - 3 hour average concentration more than once per year.
<u>Carbon Monoxide</u>	1- 9 ppm - 8 hour average concentration more than once per year. 2- 35 ppm - 1 hour average concentration more than once per year.
<u>Ozone</u>	1- 0.12 ppm - 1 hour average concentration, attained when number of days per calendar year with maximum hourly concentration greater than one is less than or equal to one.
<u>Nitrogen Dioxide</u>	1- 0.053 ppm annual arithmetic mean.
<u>Lead</u>	1- 1.5 μ/m^3 arithmetic average concentration all samples at monitoring location for calendar quarter.

Source: Lane Regional Air Pollution Authority, Title 50: Ambient Air Standards, July 12, 1988, pp. 50.1-50.2

summarizes the ambient air standards adopted by the Lane Regional Air Pollution Authority to protect the health and welfare of the citizens of Lane County, Oregon. Table 11 shows the maximum allowable ambient air quality impacts over baseline concentrations in air quality attainment areas designated as Class I, Class II, or Class III areas. The baseline concentrations are the "ambient concentration level for a regulated pollutant that existed in an area during the calendar year 1978."¹⁵⁰ Please note that there are no air quality attainment areas designated as Class III in the State of Oregon.

The nature and extent of development that may take place in an area is entirely dependent on the existing air quality in an area. The Short Mountain Methane-to-Electricity Project is fortunate to be located in an area of clean air (Class II) and as such it must meet the Prevention of Significant Air Quality Deterioration increment guidelines to maintain the air quality in the area south of the cities of Eugene and Springfield, Oregon.

Air Contaminant Discharge Permits

The Emerald People's Utility District engaged in preliminary discussions with the Lane Regional Air Pollution Authority to determine, if in fact, the Short Mountain project would be subject to review by the agency. These discussions revealed that the Short Mountain Methane-to-Electricity Project will be a major new source of air pollution that would contribute significant amounts of regulated air pollutants to the ambient air in the area of the project.¹⁵¹ As

¹⁵⁰L.R.A.P.A. § 38-005 (3).

¹⁵¹Alan Zelenka, "Personal Communication," Emerald People's Utility District, Eugene, Oregon, November 1989.

TABLE 11: Prevention of Significant Deterioration Increments

Micrograms Per Cubic Meter			
	<u>Class I</u>	<u>Class II</u>	<u>Class III</u>
<u>Particulate Matter:</u>			
TSP Annual Geometric Mean	5	19	37
TSP 24 Hour Maximum *	10	37	75
<u>Sulfur Dioxide:</u>			
Annual Arithmetic Mean	2	20	40
24 hour Maximum *	5	91	182
3 Hour Maximums *	25	512	700

Note: * The applicable maximum allowable increase may be exceeded during one such period per year at any one location.

Note: TSP = Total Suspended Particulate

Source: Lane Regional Air Pollution Authority, Title 38: New Source Review, February 13, 1990, p. 38.3

such, the project must secure authority to construct the project from the Director of the Lane Regional Air Pollution Authority and must also obtain an air contaminant discharge permit.¹⁵² A major new source may be defined as "a stationary source that emits, or has the potential to emit, any pollutant regulated under the Clean Air Act at a Significant Emission Rate."¹⁵³ A Significant Emission Rate may be defined as "emission rates equal to or greater than the amounts for air pollutants regulated under the Clean Air Act." Table 12

¹⁵²L.R.A.P.A. § 38-010 (1).

¹⁵³L.R.A.P.A. § 38-005 (8).

TABLE 12: Significant Emission Rates for Regulated Air Pollutants

Regulated Air Pollutants and Significant Emission Rates		
<u>Pollutant</u>	<u>Significant Emission Rate</u>	
Carbon Monoxide	100	tons/yr
Nitrogen Oxides	40	tons/yr
Particulate Matter	25	tons/yr
PM ₁₀	15	tons/yr
Sulfur Dioxide	40	tons/yr
Volatile Organic Compounds	40	tons/yr
Lead	0.6	tons/yr
Mercury	0.1	tons/yr
Beryllium	0.0004	tons/yr
Asbestos	0.007	tons/yr
Vinyl Chloride	1	tons/yr
Fluorides	3	tons/yr
Sulfuric Acid Mist	7	tons/yr
Total Reduced Sulfur (including hydrogen sulfide)	10	tons/yr
Reduced Sulfur Compounds (including hydrogen sulfide)	10	tons/yr

For pollutants not listed above, the Lane Regional Air Pollution Authority shall determine the rate that constitutes a significant emission rate.

Source: Lane Regional Air Pollution Authority, Title 38: New Source Review, February 13, 1990, Section 38-012

summarizes the Significant Emission Rates for the air pollutants regulated under the Clean air Act.¹⁵⁴

The Short Mountain Methane-to-Electricity Project will emit air pollution at the "Significant Emission Rates" for the regulated air pollutants, carbon

¹⁵⁴L.R.A.P.A. § 38-005 (12).

monoxide, nitrogen oxides, and hydrocarbons.¹⁵⁵ Carbon monoxide emissions of 106.9 tons/yr, nitrogen oxides emissions of 112.5 tons/yr, and hydrocarbon emissions of 112.5 tons/yr, are significant emission rates under the Lane Regional Air Pollution Authority's guidelines listed in Table 12.¹⁵⁶

In order to restore and maintain Lane County Air Quality in a condition as free from air pollution as is practicable, consistent with the overall public welfare of the county, it is the policy of the Lane Regional Air Pollution Authority to require a permit to discharge air contaminants from certain sources. As a result, no person shall construct, install, establish, modify, enlarge, develop, or operate an air contaminant discharge source listed in Table A, without first obtaining a permit from the Authority to discharge air contaminants.¹⁵⁷

Commercial electric power generation or cogeneration plants are listed as an air contaminant discharge source subject to obtaining an air contaminant discharge permit from the Lane Regional Air Pollution Authority prior to construction.¹⁵⁸ The Lane Regional Air Pollution Authority guidelines require that the following information be included in the air contaminant discharge permit application.

- A. Name, address, and nature of business;
- B. A description of the production processes and a related flow chart;

¹⁵⁵Emerald People's Utility District, Short Mountain Landfill Methane-to-Electricity Project Air Contaminant Discharge Permit Application for Lane Regional Air Pollution Authority, Eugene, Oregon, February 14, 1990, Appendix A, p. 28.

¹⁵⁶Ibid.

¹⁵⁷L.R.A.P.A. § 34-001.

¹⁵⁸Lane Regional Air Pollution Authority, Title 34 - Air Contaminant Discharge Permits, Springfield, Oregon, January 9, 1990, Table A, p. 7.

- C. A plot plan showing the location of all air contaminant sources, all discharge points, and the surrounding residential and commercial property;
- D. Type and quantity of fuels used;
- E. Amount, nature, and duration of all emissions of air contaminants;
- F. Estimated efficiency of air pollution control equipment;
- G. Other pertinent information required by the Authority.¹⁵⁹

The commercial electric power generation plants are required to pay an air contaminant discharge permit application filing fee of \$75.00, an application processing fee of \$585.00 and a fee for an annual compliance determination by the Lane Regional Air Pollution Authority of \$1005.00.¹⁶⁰ The duration of air contaminant discharge permits may vary, but the duration "shall not exceed ten (10) years."¹⁶¹ The Short Mountain Landfill Methane-to-Electricity Project Air Contaminant Discharge Permit Application for the Lane Regional Air Pollution Authority, showing the information required by the Lane Regional Air Pollution Authority, is presented in Appendix A. The text that follows is a review of the "Top-Down" Best Available Control Technology (BACT) analysis currently required of new sources of air pollutants in the air contaminant discharge permit application.¹⁶² The BACT analysis will be presented as it was applied in the Emerald People's Utility District's Short Mountain Landfill Methane-to-Electricity Project air contaminant discharge permit application.

¹⁵⁹L.R.A.P.A. § 34-010 (1) (A-G).

¹⁶⁰Lane Regional Air Pollution Authority, Title 34 - Air Contaminant Discharge Permits, Springfield, Oregon, January 9, 1990, Table A, p. 7.

¹⁶¹L.R.A.P.A. § 34-020 (1).

¹⁶²L.R.A.P.A. § 38-010 (2) (D).

Top-Down Best Available Control Technology

The United States Environmental Protection Agency has published a guidance document to aid in the "performance of analyses leading to determination of best available control technology under the prevention of significant air quality deterioration program."¹⁶³ The requirement of best available control technology is defined by the Environmental Protection Agency as:

An emissions limitation (including visible emission standard) based on the maximum degree of reduction for each pollutant subject to regulation under the Clean Air Act which would be emitted from any proposed major stationary source or major modification which the Administrator, on a case-by-case basis, taking into account energy, environmental, and economic impacts and other costs, determines is achievable for such source or modification through application of production processes or available methods, systems, and techniques, including fuel cleaning or treatment or innovation fuel combustion techniques for control of such pollutant. In no event shall application of best available control technology result in emissions of any pollutant that would exceed the emissions allowed by any applicable standard. . .¹⁶⁴

The Environmental Protection Agency interprets the best available control technology definition as containing two key requirements that must be met by any BACT determination. The best available control technology analysis must include a consideration of the most stringent air pollution control technologies that provide for a maximum reduction in emissions. A decision by the air contaminant discharge permitting agency to require lesser emission reductions

¹⁶³U. S. Environmental Protection Agency, "Top-Down" Best Available Control Technology Guidance Document, Durham, North Carolina, March 15, 1990, p. 1.

¹⁶⁴Ibid.

must be justified by an objective analysis of energy, environmental, and economic impacts. The source-specific analysis must demonstrate that the most stringent controls are not achievable due to unfavorable impacts in these areas.¹⁶⁵

The BACT analysis must be included in the record of decision by the agency for the issuance or denial of the air contaminant discharge permit.¹⁶⁶ Permitting authorities are to exercise their informed judgment in accepting or rejecting the best available control technology determination analysis.¹⁶⁷ The adoption by the Environmental Protection Agency of a top-down approach to BACT analysis reflects the agency's concern that prior approaches were deficient in fulfilling the best available control technology requirements under the Clean Air Act. The agency is hopeful that its latest top-down approach and guidance document will be more effective in assuring national compliance with the new source requirements of the Clean Air Act.¹⁶⁸ Table 13 summarizes the top-down approach to the best available control technology analysis.

Short Mountain Landfill Methane-to-Electricity Project Best Available Control Technology Analysis

The Emerald PUD evaluated the following control options in its Best Available Control Technology top-down analysis; a turbocharged low emission high compression engine, a stratified charge turbocharged engine, a turbocharged

¹⁶⁵Ibid., p. 2.

¹⁶⁶Ibid., p. 2.

¹⁶⁷Ibid., p. 4.

¹⁶⁸Ibid., p. 4.

TABLE 13: Top-Down Approach to Best Available Control Technology Analysis

Key Steps in the Top-Down Approach

Step 1: Identify all control technologies.

- List should be comprehensive, including LAER (lowest achievable emission reduction) option.

Step 2: Eliminate technically infeasible options.

- A demonstration of technical infeasibility should be clearly documented and should show, based on physical, chemical, and engineering principles, that technical difficulties would preclude the successful use of the control option on the emission unit under review.

Step 3: Rank remaining control technologies by control effectiveness.

Should include:

- control effectiveness (percent pollutant removed);
- expected emission rate (tons per year)
- expected emission reduction (tons per year);
- energy impacts (BTU, kWh)
- environmental impacts (other media and the emissions of toxic and hazardous air emissions); and
- economic impacts (total cost of effectiveness and incremental cost effectiveness).

Step 4: Evaluate most effective controls and document results.

- Case-by-case consideration of energy, environmental, and economic impacts
- If top option is not selected as BACT, evaluate next most effective control option.

Step 5: Select BACT

- Most effective option not rejected is BACT.
-

Source: U. S. Environmental Protection Agency, "Top-Down" Best Available Control Technology Guidance Document, March 15, 1990, p. 8

engine with a catalytic converter, and a turbocharged engine. Each of the control options are considered technologically feasible as techniques for emission reduction. However, literature from Caterpillar, Inc., a manufacturer of spark-ignited engines for use in landfill gas operations, states that engines equipped with catalytic converters are not compatible with landfill gas. The relatively high percentage of contaminants contained in landfill gas tends to clog the catalytic converters, rendering them ineffective in reducing nitrogen oxide emissions.¹⁶⁹ The turbocharged low emission high compression engine, known as "clean-burn" technology, is currently considered BACT by the South Coast (Los Angeles) and the Bay Area (San Francisco) Air Quality Management Districts of California.¹⁷⁰ Catalytic converter equipped engines exist at several California landfill gas operations, but according to the South Coast and the Bay Area Air Quality Management Districts, are no longer considered as BACT for landfill gas to electricity projects.¹⁷¹

Top-Down Effectiveness Ranking

The top-down effectiveness ranking of the available emission control options, as determined in the analysis by the Emerald PUD, is listed as follows:

- 1.) turbocharged low emission high compression engine
- 1.) (tied) stratified charge turbocharged engine

¹⁶⁹Emerald People's Utility District, Short Mountain Landfill Methane-to-Electricity Project Air Contaminant Discharge Permit Application for Lane Regional Air Pollution Authority, Eugene, Oregon, February 14, 1990, Appendix B, p. 30.

¹⁷⁰Emerald People's Utility District, Short Mountain Landfill Methane-to-Electricity Project Air Contaminant Discharge Permit Application for Lane Regional Air Pollution Authority, Eugene, Oregon, February 14, 1990, p. 18.

¹⁷¹Ibid.

- 3.) turbocharged engine with catalytic converter
- 4.) turbocharged engine¹⁷²

The stratified charge control option has nominally lower emission rates than the low emission option. However, the emission rates in tons/horsepower of the low emission option are lower for the three regulated air pollutants under consideration (nitrogen oxides-NO_x, carbon monoxide-CO, hydrocarbons-HC). The Emerald PUD, therefore, made the decision to rank the low emission option and the stratified charge option the same in the top-down Best Available Control Technology analysis.¹⁷³ The catalytic converter-equipped engine ranked third and the turbocharged engine last in the BACT rankings.

Table 14 summarizes the Best Available Control Technology analysis done by the Emerald People's Utility District for the Short Mountain project. The turbocharged engine control option is used as an emission control baseline for determining the reduction in emissions of the other emission control technologies. Frequent references to Table 14 will be made in the following discussion of the energy and economic impacts of the various emission control technologies.

Energy Impacts

The discussion of the energy impacts on the Short Mountain electricity generation project of the BACT control technologies centers on energy penalties that are associated with the use of that particular combustion technology. From

¹⁷²Ibid., p.19.

¹⁷³Ibid., p.19.

TABLE 14: Short Mountain Project Best Available Control Technology Analysis

<u>Control Alternatives</u>		Turbocharged Engine (Baseline)	Turbocharged Engine w/ Catalytic Converter (1)	Stratified Charge Turbocharged Engine (4)	Turbocharged Low Emission High Comp. Engine
<u>Emission Rate</u>					
(tons/yr)	NOx	144.5	29.5	14.3	15.3
	CO	10.7	2.3	14.3	16.1
	HC	6.1	NA	14.3	16.8
<u>Emission Reduction</u>					
(tons/yr)	NOx	-	109.8	130.2	129.2
	CO	-	8.0	+3.6	+5.4
	HC	-	NA	+8.2	+10.8
<u>Control Efficiency</u>					
(% reduction)	NOx	-	76.0%	90.1%	89.4%
	CO	-	75.0%	+33.8%	+50.6%
	HC	-	NA	+135.1%	+177.1%
<u>Incremental Unit Cost</u>			(3)	(5)	(6)
		\$0	\$32,558	\$32,680	\$12,797
<u>Incremental Project Cost</u>		(2)			
		(\$1,116,500)	\$227,903	\$228,757	\$89,579
<u>Incremental Annual Cost</u>					
		\$0	\$17,558	\$9,680	\$0
<u>Economic Impact</u>					
(\$/ton removed)					
	NOx	-	\$297	\$251	\$99
	CO	-	\$4,068	-	-
	HC	-	NA	-	-

Note: NA = information not available

Notes:

Calculations based on an 85% availability factor, using Caterpillar G399 engines.

(1) Caterpillar literature states that catalytic converters are incompatible with landfill gas.

(2) Total capital cost for seven 600 kW Low Emission Caterpillar G399 engines.

TABLE 14: continued

-
- (3) Catalytic converter costs include:
- a. \$10,000 for the converter casing (one time cost)
 - b. \$5,000 for the initial set of internal beads
 - c. \$15,000 for three additional bead changes per year
 - d. 4 hours downtime per month for bead washing:
 $((4 \text{ hrs})(1,813 \text{ kWh/hr})(\$0.0156/\text{kWh})(12 \text{ months}) = \$1,358/\text{year})$
 - e. 4 hours labor per month for bead washing:
 $((4 \text{ hrs})(\$25/\text{hr})(12 \text{ months}) = \$1,200/\text{year})$
- (4) Emissions from a smaller engine (870 hp) than the Low Emission engines (930 hp).
- (5) Cost to retrofit a turbocharged engine (\$23,000), and the associated 9% power loss due to the retrofit $((13,500,000 \text{ kWh per year}/3 \text{ units})(9\% \text{ power loss})(\$0.0239/\text{kWh}) = \$9,680/\text{year})$.
- (6) Additional capital cost to modify a standard turbocharged engine.
-

Source: Emerald People's Utility District, Short Mountain Landfill Methane-to-Electricity Project Air Contaminant Discharge Permit Application for Lane Regional Air Pollution Authority, February 14, 1990, p. 20

the figures in Table 14, one can ascertain that no energy penalties are associated with the use the turbocharged engine and the turbocharged low emission engine control technologies.¹⁷⁴

The catalytic converter technology requires a project shut-down period of at least four hours per month to change the internal beads in the converters. An energy loss to the project of approximately 1%, over 82,000 kWh of electricity, will result from these monthly maintenance shut-downs. The 1% energy penalty is, however, within the normal range for the technologies under consideration.¹⁷⁵

¹⁷⁴Ibid., p. 21.

¹⁷⁵Ibid., p. 21.

The stratified charge engine technology carries with it a 9% reduction in engine horsepower, when compared with the standard turbocharged engine. This reduction in engine horsepower translates to a loss of 1,215,000 kWh of electricity per year for the generation project. The Emerald PUD deemed the 9% energy penalty of the stratified charge technology to be outside the normal range of energy loss for the technologies under consideration in the BACT analysis.¹⁷⁶

A technology's incremental energy costs for reduction of emissions must be considered under energy impacts. This excerpt from the Emerald People's Utility District's BACT analysis sums up the incremental energy costs as shown in Table 14.

For NO_x, the low emission engine has an incremental energy cost of 5.88 kW per ton of NO_x reduced, 16% better than the stratified charge engine's incremental energy cost of 5.08 kW per ton of NO_x removed. The catalytic converter option is 31.5% better (6.68 kW per ton of NO_x reduced) than the stratified charge engine and 13.6% better than the low emission engine.¹⁷⁷

Economic Impacts

The low emission engine technology option has the lowest unit incremental cost, the lowest project incremental cost, and no annual incremental cost (from Table 14). Expressed in dollars per ton of NO_x reduced, the economic impact of the technology (\$99 per ton of NO_x reduced) is the lowest of the technologies under consideration. The stratified charge engine and the turbocharged engine with a catalytic converter have considerably higher unit

¹⁷⁶Ibid., p. 21.

¹⁷⁷Ibid., p. 21.

incremental costs, project incremental costs, and annual costs for the generation project. From Table 14, the economic impact of the stratified charge engine is \$251 per ton of NO_x reduced and that of the catalytic converter equipped engine is \$297 per ton of NO_x reduced.¹⁷⁸

The following summary of the economic impacts of the emission control options is taken from the Emerald People's Utility District's BACT analysis in the Short Mountain Landfill Methane-to-Electricity Air Contaminant Discharge Permit Application for the Lane Regional Air Pollution Authority.

The incremental cost of the catalytic converter option is over 2.5 times that of the low emission engine with less of a reduction in NO_x emissions (76% versus 89.4%), but more of a reduction in CO. The cost per ton of NO_x reduced is three times greater than the low emission engine, and the annual cost per unit is substantially higher. This technology is no longer BACT in California, partly because of the substantial cost difference with low emission engines.

The incremental cost and the cost per ton of NO_x reduced for the stratified charge option is also over 2.5 times that of the low emission option, with the reduction in tons of NO_x nearly equal. The increase in CO is 42% less than that from the low emission engine, and the hydrocarbon increase is 18% less. The project incremental cost is also 2.5 times that of the low emission engine, and the annual incremental cost is substantial to the project. Since the emission reductions and increases for the stratified charge option are nearly the same as the low emission engine option, we consider the cost for the stratified charge option to be disproportionately high, as compared to the low emission option.¹⁷⁹

¹⁷⁸Ibid., p. 23.

¹⁷⁹Ibid., p. 23.

Environmental Impacts

According to the U.S. Environmental Protection Agency, the evaluation of environmental impacts in the Best Available Control Technology analysis must include:

. . . significant or unusual other media impacts (e.g., water or solid waste), and, at a minimum, the impact of each control alternative on emissions of toxic or hazardous air contaminants.¹⁸⁰

The Emerald PUD's analysis of environmental impacts indicated that the low emission engine, the stratified charge engine, and the turbocharged engine control alternatives pose no significant or unusual other media environmental impacts. The catalytic converter technology option does, however, pose a significant impact on water pollution.¹⁸¹ Additionally, none of the control alternatives have toxic or hazardous air contaminant emissions associated with their use. Each of the control alternatives succeeds the gas-clean up and compression equipment in the flow of the landfill gas through the system and will have no impact on the quantity or quality of the landfill gas condensate discharged from the system.¹⁸²

The internal beads from the catalytic converter must be washed on a monthly basis to remove contaminants absorbed from the landfill gas. Traces of heavy metals and concentrations of the pollutants absorbed by the beads in

¹⁸⁰U. S. Environmental Protection Agency, "Top-Down" Best Available Control Technology Guidance Document, Durham, North Carolina, March 15, 1990, p. 10.

¹⁸¹Emerald People's Utility District, Short Mountain Landfill Methane-to-Electricity Project Air Contaminant Discharge Permit Application for Lane Regional Air Pollution Authority, Eugene, Oregon, February 14, 1990, p. 22.

¹⁸²*Ibid.*, p. 22.

normal operation will be contained in the fluid used to wash the beads. Disposal of the waste fluid from the monthly washing procedure will present a water waste disposal problem. In addition, the catalytic converter's internal beads must be entirely replaced and disposed of every three months, posing yet another environmental impact of some concern.¹⁸³

Best Available Control Technology Justification

As a result of its analysis, the Emerald PUD proposed the low emission engine technology as the Best Available Control Technology (BACT) option for the Short Mountain Landfill Methane-to-Electricity Project.¹⁸⁴ According to the utility, the low emission engine technology "offers the best combination of emission reduction levels, energy impacts, environmental impacts, and economic impacts."¹⁸⁵

The BWR Associates, Inc., of Medford, Oregon, performed the air quality impact modeling for the project "to demonstrate that impacts from the project will not prevent maintenance of the National Ambient Air Quality Standards (NAAQS), or cause, or contribute to, violations of the NAAQS standards."¹⁸⁶ The environmental consulting firm ran an Atmospheric Dispersion Model, in accordance with the U.S. Environmental Protection Agency's EPA-450/2-78-027R (July 1986) Guideline on Air Quality Models. The purpose of the modeling is to

¹⁸³Ibid., p. 22.

¹⁸⁴Ibid., p. 25.

¹⁸⁵Ibid., p. 26.

¹⁸⁶BWR Associates, Inc., Emerald People's Utility District: Modeling for Short Mountain Project # 90-010M, Medford, Oregon, February 7, 1989, p. 2.

determine the impact of nitrogen oxide emissions from the project on the surrounding area's air quality.¹⁸⁷

Section 3.1 of the report summarizes the findings of the air quality modeling for nitrogen oxides emission impacts. The report, as quoted from the Emerald People's Utility District's air contaminant discharge permit application, states that:

There is no ambient air quality data available for this area. Nitrogen dioxide monitoring data from Portland was used to provide a 'generic' background concentration of 0.019 ppm.

One hour impact predictions were converted to annual averages by multiplying by a conservative factor of 0.15. This procedure has been accepted by the Oregon Department of Environmental Quality.

Results of this modeling indicate a maximum annual off-site impact of fifty-three (53) micrograms per cubic meter. This concentration is equal to 0.028 ppm, which, when added to the 0.019 ppm 'background' is 0.047 ppm. This is less than the National Ambient Air Quality Standard of 0.053 ppm.¹⁸⁸

As the air quality modeling was done using emission data from the low emission engine technology option, one may draw the conclusion that the Short Mountain project using this technology as BACT will not cause the area to exceed National Ambient Air Quality Standards.¹⁸⁹

The Emerald PUD feels that by developing this project the odor and greenhouse gases (carbon dioxide and methane) escaping from the landfill will

¹⁸⁷Ibid., p. 3.

¹⁸⁸Emerald People's Utility District, Short Mountain Landfill Methane-to-Electricity Project Air Contaminant Discharge Permit Application for Lane Regional Air Pollution Authority, Eugene, Oregon, February 14, 1990, p. 4.

¹⁸⁹Ibid., p. 25.

be almost eliminated. A reduction in 1991 of nearly 400 million cubic feet per year of methane and 260 million cubic feet per year of carbon dioxide produced from the landfill will result from the landfill gas recovery project. These reductions in greenhouse gases can be expected to double by the year 2007.¹⁹⁰

The significant economic, energy, and environmental impacts of the other alternatives preclude their selection as the Best Available Control Technology for the Short Mountain Methane-to-Electricity Project. In addition, the catalytic converter technology is not presently considered compatible with landfill gas operations and the stratified charge technology is relatively new and unproven. The low emission engine technology as BACT will allow the Short Mountain Project to produce significant benefits for the area, while maintaining the region's air quality. Therefore, there is considerable justification for naming the low emission technology as Best Available Control Technology for this electricity generation project.¹⁹¹

Acceptance of Best Available Control Technology

The Lane Regional Air Pollution Authority accepted the low emission high compression engines as Best Available Control Technology for the Short Mountain Project in late March 1990. The Authority issued an air contaminant discharge permit for the project after the necessary 30 day public notice and comment period on the application.¹⁹² The Emerald People's Utility District's permit will be valid for a period of ten (10) years, with the provision that the

¹⁹⁰Ibid., p. 25.

¹⁹¹Ibid., pp. 25-26.

¹⁹²L.R.A.P.A. § 34-010 (4).

utility install monitoring equipment at the site and continue to monitor NO_x emissions from the project's engines.¹⁹³

Noise Pollution

In the State of Oregon, noise is recognized as a form of pollution that is transmitted through the air. Noise control standards have been set for industrial and commercial noise emissions, as well as for other noise generating activities. The standards are set to protect the public from adverse health effects of noise and to protect the public's welfare. The State of Oregon's noise level standards for industrial and commercial noise emissions are shown in Table 15 on the following page.

The low emission engines used in the Emerald People's Utility District's Short Mountain Landfill Methane-to-Electricity Project will be outfitted with 40 dBA mufflers to comply fully with the existing noise level standards for industrial and commercial activities.¹⁹⁴

¹⁹³Alan Zelenka, "Personal Communication," Emerald People's Utility District, Eugene, Oregon, January 1990.

¹⁹⁴Ibid.

TABLE 15: Oregon Commercial and Industrial Noise Standards

Allowable Statistical Noise Levels in Any One Hour		
Level	7:00 a.m. to 10:00 p.m.	10:00 p.m. to 7:00 a.m.
L50	55 dBA	50 dBA
L10	60 dBA	55 dBA
L1	75 dBA	60 dBA

Notes: L50 is the level that may be exceeded 50% of the time; cumulative 30 minutes/hour.

L10 is the level that may be exceeded 10% of the time; cumulative 6 minutes/hour.

L1 is the level that may be exceeded 1% of the time; cumulative 36 seconds/hour.

dBA means A-weighted decibels (decibels measured at the frequency where the human ear is most sensitive).

Source: Oregon Department of Environmental Quality, Air Quality Control Division, 1989 Oregon Air Quality Annual Report, July 1990, p. 21

CHAPTER VI

CONCLUSION

Will Landfill Gas-to-Energy Work?

The development of a landfill gas recovery to energy project such as the Emerald People's Utility District's Short Mountain Landfill Methane-to-Electricity Project must be carefully planned and executed. Planning such a project does not make economic or environmental sense unless there is a profitable end use for the gas or environmental regulations that require landfill gas collection. The planned development of the Short Mountain Landfill Methane-to-Electricity Project makes sense on the first point and will soon fulfill the second point.

On September 26, 1989, the Emerald People's Utility District, in Eugene, Oregon, gave notice to Lane County that the Short Mountain Landfill Methane-to-Electricity Project is 'economically suitable' for development. At start up, in 1990, we estimate generation of between 10-14 million kWhs (kilowatt hours) and approximately 2 MWs (megawatts) annually. Initially, the project would provide electricity to between 700 and 900 homes. Because Short Mountain is a new landfill with a remaining life of about 40 years, the project will start small and grow incrementally until it peaks out at about the year 2006 generating between 31-34 million kWhs and approximately 5 MWs. Ultimately, the project should provide the electricity for between 2100 and 2200 homes.¹⁹⁵

¹⁹⁵Emerald People's Utility District, Short Mountain Landfill Methane-to-Electricity Project Air Contaminant Discharge Permit Application for Lane Regional Air Pollution Authority, Eugene, Oregon, February 14, 1990, p. 1.

The United States Environmental Protection Agency (EPA) will issue new guidelines concerning landfill gas emissions and migration from existing municipal solid waste sanitary landfills sometime in 1991. The new emission guidelines will be promulgated under § 111 of the Clean Air Act. Depending on the final form of the new guidelines, a landfill the size of the Short Mountain Landfill may be required to recover landfill gas and dispose of it to meet the new landfill gas emission and migration guidelines.¹⁹⁶ Upon the adoption of the new guidelines, the Short Mountain Landfill Methane-to-Electricity Project will meet the second criterion, that of environmental regulations.

Recipe for Development

The Waste Management of North America, a major developer of landfill gas-to-energy recovery projects in the United States, has developed a recipe to follow in planning and developing landfill gas projects. The recipe is as follows:

1. Determine quantity of recoverable gas.
2. Identify potential customers.
3. Get community support.
4. Perform economic analysis.
5. Negotiate energy sales contract.
6. Obtain construction and operating permits.
7. Specify and order equipment.
8. Hire site-specific design engineer and installation contractor.
9. Establish operating, maintenance, and safety procedures.
10. Begin construction.
11. Hire and train plant operations and maintenance personnel.
12. Monitor and report performance.¹⁹⁷

¹⁹⁶Fred Dimmick and Alice Chow, Environmental Protection Agency, and others, USEPA Clean Air Act Regulation for Landfill Gas Emission, Durham, North Carolina, March 1990, p. 10.

¹⁹⁷Greg Maxwell, Waste Management of North America, "Will Gas-to-Energy work at Your Landfill?" Solid Waste & Power, June 1990, p. 44.

The Short Mountain Landfill Methane-to-Electricity Project followed this recipe in its developmental stages and will continue to follow it as operations commence. As has been clearly demonstrated in this manuscript, the job of the resource planner is a long and complex series of tasks involving the balancing of tradeoffs between energy potential and the environmental costs and benefits of landfill gas to energy development.

Landfill Gas's Energy Benefits and Environmental Degradation Potential

The Waste Management of North America currently operates 20 landfill gas-to-energy recovery plants, with plans to develop 16 more landfill gas recovery operations in the near future. The company estimates that its landfill gas recovery projects save the energy equivalent quantity of approximately 1.6 million of oil per year (1990 figures).¹⁹⁸ Table 16 shows the Waste Management of North America's projected energy sales for 1990 and the equivalent quantities of oil, natural gas, and coal saved for the year.

According to the Governmental Advisory Associates (GAA), there are currently 77 landfills (1988 figures) in the United States recovering landfill gas and selling the energy value.¹⁹⁹ It is not hard to see that the amount of oil equivalent energy recovered by these projects is enormous and given the new EPA landfill gas emission and migration guidelines, the future recoverable energy potential from landfill gas will grow as more and more landfills are required to install landfill gas recovery systems.

¹⁹⁸Ibid., p. 44.

¹⁹⁹Governmental Advisory Associates, 1988-89 Methane Recovery from Landfill Yearbook, New York, 1988, p. xv.

TABLE 16: Waste Management's Projected Energy Sales for 1990

Projected 1990 Energy Sales
Total Landfill Gas Sales = 17,280 Million Cubic Feet
Total Electrical Power Sales = 461,500,000 Kilowatt Hours
Equivalent Quantity of Oil = 1,600,000 Barrels
Equivalent Quantity of Natural Gas = 8,640 Million Cubic Feet
Equivalent Quantity of Coal = 313,000 Tons

Source: Greg Maxwell, Waste Management of North America, "Will Gas-to-Energy work at Your Landfill?" Solid Waste & Power, June 1990, p. 46

The Environmental Protection Agency estimates that there are approximately 38,000 municipal solid waste landfills in the United States. Of these, 32,000 are closed and over 6000 are still active (accepting waste).²⁰⁰ Projected emissions from the active 7,124 landfills (including 1,090 landfills expected to close between 1987 and 1992) are 300,000 Mg/yr (megagrams per year) of nonmethane organic compounds and 15,000,000 Mg/yr (megagrams per year) of methane.²⁰¹ The vast energy related benefits and the equally harmful potential for environmental degradation caused by this quantity of methane from landfills in the United States cannot be ignored.

The Oregon Task Force on Global Warming, in its June 1990 Report to the Governor and the Legislature, states that a molecule of methane (with a lifespan of 10 years) contains 3.7 times the global warming potential of a molecule of

²⁰⁰Fred Dimmick and Alice Chow, Environmental Protection Agency, and others, USEPA Clean Air Act Regulation for Landfill Gas Emission, Durham, North Carolina, March 1990, p. 2.

²⁰¹*Ibid.*, p. 10.

carbondioxide.²⁰² Khalil and Shearer, in a May 1990 report to the Oregon Department of Energy, estimate that landfills contribute over 3300 Gigagrams per year of methane to the methane inventory of the United States.²⁰³ The combination of these two facts should be cause for great concern among the citizens of the United States and the world.

Given the contribution of nonmethane organic compounds in the formation of ozone, the contribution of methane to global warming, the potentially harmful health effects of landfill emissions, the odor nuisance of landfill gas, and the fire and explosion hazards associated with landfill gas emissions, we cannot afford to ignore the environmental impacts this potent source of energy brings when not properly controlled. The environmental costs and benefits of developing this source of energy have been well established in this manuscript, as have the negative effects of the lack of proper landfill gas control.

Landfill Gas Recovery Potential in Oregon

Much of the information concerning landfill gas recovery potential in the State of Oregon dates back to the early 1980's and is somewhat sketchy in nature. The Oregon Department of Energy estimated in 1983 that only two landfills in Oregon were capable of producing sufficient methane to be recovered for energy uses. The St. John's Landfill, Portland, and the Rossman's Landfill, Oregon City,

²⁰²Oregon Task Force on Global Warming, Report to the Governor and Legislature, Salem, Oregon, June 1990, p. 1-4.

²⁰³M.A.K. Khalil, and M.J. Shearer, Oregon Methane and Nitrous Oxide Inventories, Andarz Co. Contract No. C91067, prepared for the Oregon Department of Energy, Salem, Oregon, May 1990, p. 9.

were determined to be the only landfills in the state with sufficient depth and refuse in place to make landfill gas to energy projects feasible.²⁰⁴ The Short Mountain Landfill, Eugene, the Coffen Butte Landfill, Linn County, and the Newburg Landfill, Yamhill County, were added to this list in 1986.²⁰⁵ The Oregon Department of Energy then (1986) estimated a total annual landfill gas production potential of 1.910 billion cubic feet per year from these landfills, with a calculated electricity generation potential of 73.5 million kilowatts per year.²⁰⁶

Oregon Waste Systems, Inc., a subsidiary of Waste Management of North America, now operates a 2000 acre landfill in Gilliam County, Oregon, approximately 10 miles southwest of Arlington in far eastern Oregon. The site is now accepting over 2000 tons of refuse per week, but it will be many years before landfill gas recovery for commercial purposes will be feasible. The area receives less than nine inches of rain a year, so despite the landfill's huge size, the refuse may not reach the proper level of moisture content for the commercial production of landfill gas.²⁰⁷

The Emerald People's Utility District's Short Mountain Landfill Methane-to-Electricity Project near Eugene, Oregon is currently the only active landfill gas to electricity project under development in State of Oregon. Rossman's Landfill in Oregon City recovers landfill gas, approximately 1 million cubic feet per day of methane after removal of carbon dioxide, that is pumped into the pipeline grid

²⁰⁴Greg Marsh, P.E., Oregon Department of Energy White Paper: Energy Recovery Opportunities From Oregon's Solid Waste, Oregon Department of Energy, Salem, Oregon, December 8, 1983, p. 12.

²⁰⁵Donald Bain, Internal Memo, Oregon Department of Energy, Salem, Oregon, October 1986, p. 1.

²⁰⁶*Ibid.*

²⁰⁷Sydney Stephenson, "Landfill in the Sun," Visions, Fall 1989, p. 26-27.

of the Northwest Natural Gas Company.²⁰⁸ A similar landfill gas recovery operation is in place at the 31 acre Newburg Landfill in Yamhill County.²⁰⁹ A commercial landfill gas recovery project at the St. John's Landfill in Portland failed to materialize because the landfill gas in place has apparently migrated outside the landfill or otherwise been depleted.²¹⁰

²⁰⁸Vince Kohler, "Long-awaited Technology Puts Gulls Out of Work," The Oregonian, Portland, Oregon, September 19, 1984, p. B-2.

²⁰⁹"BioGas Plant Slated," The Oregonian, Portland, Oregon, June 12, 1985, p. D-1.

²¹⁰Alex Sifford, "Personal Communication," Oregon Department of Energy, Salem, Oregon, June 1990.

APPENDIX

AIR CONTAMINANT DISCHARGE PERMIT APPLICATION



Short Mountain Landfill
Methane-to-Electricity Project
Air Contaminant Discharge
Permit Application
For
Lane Regional Air Pollution Authority

Emerald Public Utility District
33733 Seavey Loop Road
Eugene, Oregon 97405
Contact: Alan Zelenka
(503)-746-1583

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INTRODUCTION

On September 26, 1989 Emerald People's Utility District, in Eugene, Oregon, gave notice to Lane County that the Short Mountain Landfill methane-to-electricity project is "economically suitable" for development. At start-up, in 1990, we estimate the generation of between 10-14 million KWhs and approximately 2 MWs annually¹. Initially, the project would provide electricity to between 700 and 900 homes. Because Short Mountain is a new landfill with a remaining life of about 40 years the project will start small and grow incrementally until it peaks out at about the year 2006 generating between 31-34 million kWhs and approximately 5 MWs. Ultimately the project should provide the electricity for between 2100 and 2200 homes.

This project began development in 1985 when Emerald approached Lane County. In November 1988, Emerald's Resource Planning Citizen's Advisory Committee, a ratepayer committee charged with recommending to Emerald's Board a resource strategy, recommended development of the project. Emerald's Board of Directors approved development on July 25, 1989. If all goes well, and the weather is cooperative, Emerald could begin construction in 1990 with generation by late 1990.

While this project will be unique in the Northwest, the technology is not new. In 1988 there were 87 operating projects in the U.S. with an additional 68 projects in various stages of development. These 155 projects will generate 378 MWs annually. To our knowledge, this is the first and only electric generation project of its kind in the Pacific Northwest.

The Short Mountain project also has many benefits to the Pacific Northwest, Emerald, and the local community. Being a renewable resource, it is consistent with the resource priorities of the State Energy Plan and the Northwest Power Planning Council's Plan. Since development of the resource will be in small incremental steps with short lead times using known technology the risk and uncertainty of the project is relatively small. Additionally, this project will help reduce greenhouse gases (carbon dioxide and methane) escaping from the landfill. Most importantly, Short Mountain is a low cost resource that will help keep rates stable. Using the Northwest Power Planning Council's methodology the initial phase of Short Mountain will have a levelized cost of 19-21 mills, less than the levelized cost of BPA power using current rate projections, and is as low or lower than most conservation.

¹ KWh is the measure of energy used over time, and MW (or 1000 kW) is the instantaneous measure of energy used.

PROCESS DESCRIPTION

Emerald PUD will extract naturally occurring methane from the Short Mountain Landfill through wells drilled down into the landfill. The wells will be connected, through a system of plastic pipe (HDPE - High Density Polyethylene), directly to large internal combustion engines (900 horsepower) where the landfill gas will be burned to generate electricity. The flow chart on the next page graphically demonstrates the process.

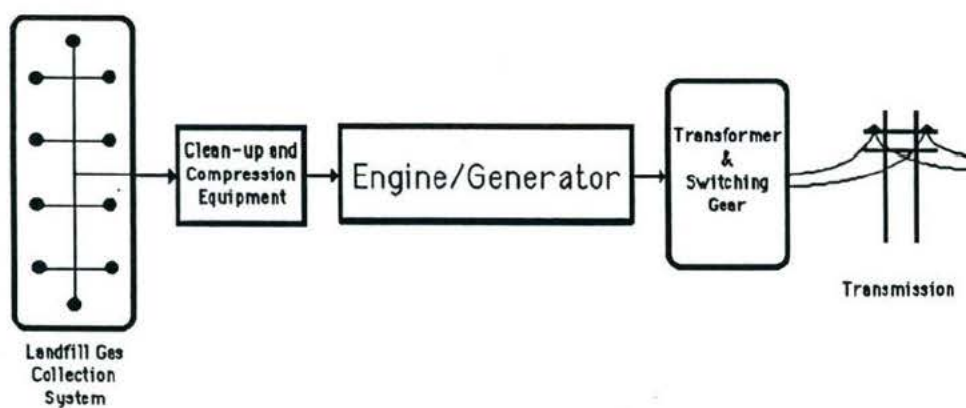
A total of approximately thirty-two wells will be drilled 200 feet apart down to the landfill bottom or when water/leachate is encountered. Twenty of the wells will be drilled to approximately 30 feet deep in the lower portion of the fill area, and twelve wells of approximately 80 feet deep are planned for the upper fill area. The landfill gas will be extracted from the individual wells and piped through the HDPE collection system to the electrical generation site. Prior to combustion in the engines, the gas will pass through a gas clean-up system which removes the moisture and filters out particulates and other impurities. After the gas is cleaned, it will be compressed to approximately 25-30 p.s.i. and injected into the engine carburetors.

Combustion of the gas in the engines will produce power to drive the electric generators. Through switching gear and a step-up transformer, the electricity is tapped directly into the utility grid for use by Emerald's customers.

It should be noted that development of this project as outlined will significantly decrease odor problems, and the off-gassing of greenhouse gases (methane and carbon dioxide). We estimate a reduction in 1991 of nearly 400,000,000 cubic feet per year of methane and 260,000,000 cubic feet per year of carbon dioxide. This amount would more than double by the year 2007 when the landfill's gas production peaks. Instead, this gas will be burned and transformed to predominantly nitrogen oxides, carbon monoxide, and hydrocarbons, the environmental impacts of which are described in detail in this analysis.

FLOW CHART

SHORT MOUNTAIN PROJECT



COMPLIANCE WITH STATE & FEDERAL AAQS

BWR ASSOCIATES, INC.
AIR QUALITY MODELING

The following summary is taken from the BWR Associates' Air Quality Modeling Report for the Short Mountain project, section 3.1. The complete report is included as Appendix D, under separate cover.

"There is no ambient air quality data available for this area, Nitrogen Dioxide monitoring data from Portland was used to provide a 'generic' background concentration of 0.019 ppm.

One hour impact predictions were converted to annual averages by multiplying by a conservative factor of 0.15. This procedure has been accepted by ODEQ.

Results of this modeling indicate that a maximum annual off-site impact of fifty three (53) micrograms per cubic meter. This concentration is equal to 0.028 ppm, which, when added to the 0.019 ppm 'background' is 0.047 ppm. This is less than the AAQS standard of 0.053 ppm."

APPLICATION FOR AIR CONTAMINANT
DISCHARGE PERMIT

LANE REGIONAL AIR POLLUTION AUTHORITY
225 North 5th, Suite 501
Springfield, OR 97477
(503) 726-2514

FOR LRAPA USE:
Permit No. _____
Invoice No. _____

APPLICATION FOR AIR CONTAMINANT DISCHARGE PERMIT

The applicant named below hereby submits this completed application and requests that the source site described herein be issued an Air Contaminant Discharge Permit for the air contaminant source(s) named in Item 1 below:

1. Air contaminant source(s) and fees as listed in the Lane Regional Air Pollution Authority Rules, Title 34, for your operation are shown below. Complete and attach the information for each source as required by Schedules I, II, and III of this application.

Air Contaminant Source	SIC*	AIPID Fee**	PCD Fee***
a. (7) Landfill gas fired electric power generation	4911	\$585	\$1,005
b. (Potentially 1) Stand by flare	4911	-	-
c. (See Table 1 for the schedule of Genset additions.)			

2. Official Applicant Identification

Firm Name Emerald PUD
Division _____
Mailing Address 33733 Seavey Loop Rd
City Eugene State OR Zip 97405
Phone (503) 746-1583 Ext. _____

3. Status of Applicant:
(Please check the one that applies)

☐ Lessee
☐ Partnership
☐ Corporation
☐ Individual Owner
☒ Government Agency

4. Name and Address of the Owner, Partner, or Corporation's Registered Agent:

Name Same as above
Title _____
Mailing Address _____
City _____ State _____ Zip _____
Phone () _____ Ext. _____

5. Person Authorized to Receive Permit:

Name Lon Topaz
Title General Manager
Mailing Address 33733 Seavey Loop Rd
City Eugene State OR Zip 97405
Phone (503) 746-1583 Ext. _____

6. Source Site Location:

Plant Site Address: Lane County's
Short Mountain Landfill
City Lane County State OR Zip 97405
Phone () _____ Ext. _____

7. Person to Contact (at plant site):

Name _____
Title _____
Plant Address _____
City _____ State _____ Zip _____
Phone () _____ Ext. _____

8. Certification: I hereby certify that the information contained in this application, schedules, and exhibits is true and correct to the best of my knowledge. Submitted with this application is a check made payable to: LANE REGIONAL AIR POLLUTION AUTHORITY in the amount of \$ 1,665 for total AIPID fee, PCD fee, and a \$75.00 filing fee.

Samuel Lopez
(Signature of Owner or Legally Authorized Representative)
General Manager (Title) 2/14/90 (Date)

- * Standard Industrial Classification Number
** Application, Investigation and Permit Issuing or Denying Fee
*** Permit Compliance Determination Fee (paid annually)

Application for Air Contaminant Discharge Permit

Schedule I - General Description of Air Contaminant Source

The information required in this schedule must be furnished for each air contaminant source listed in Item 1, Page 1 of this application. If an existing facility has a current application on file with LRAPA data may be referenced.

(7) Landfill gas fired electric power generation

1. Source (as listed in Item 1) (Potentially 1) Stand by flame
2. Air Contaminant source process production rate as generally stated in the industry: Kilowatt hours (KWH), cubic feet per hour.

- a. Primary operating schedule of source: *
24 hours per day 7 days per week 52 weeks per year
- b. Annual quantity of major material(s) introduced into the process:

Material	Annual Input
<u>See Table 2 (attached)</u>	

- c. Maximum hourly output production rate: 600 KW
- d. Normal hourly output production rate: 600 KW

* Emerald assumes an 85% availability factor.

Schedule II - Detailed Description of Air Contaminant Source

(SEE ATTACHMENTS)

1. Exhibit A - Process Flow Diagram for the Air Contaminant Source Listed in Item 1:

Attach as Exhibit "A" a process flow diagram showing relationship of process equipment, operating schedule of process equipment in hours per day, days per week, and weeks per year (if seasonal, indicate normal season), and their respective air contaminant discharge points--include transfer equipment (e.g., capped cyclone). Each air contaminant discharge point must be referenced with a unique descriptive item name.

List for each air contaminant discharge point and each piece of air contaminant control equipment appearing in the process flow diagram, and delineate the following information:

- a. Unique descriptive item name for each air contaminant discharge point.
- b. Description of all types of material and quantity handled by the control equipment.
- c. Height above ground of air contaminant discharge point.
- d. Cyclone diameter and length or other air discharge outlet dimension (e.g., stack).
- e. Air flows handled by the control equipment in standard cubic feet per minute (if known). Otherwise, submit inlet pipe dimension of control equipment.
- f. Velocity of air at control equipment outlet in feet per minute (if known). Otherwise, submit outlet dimension of control equipment.
- g. Temperature of control equipment exhaust air.
- h. Indicate whether discharge outlet is vertical or horizontal.
- i. For fuel burning equipment and/or incineration equipment, include types of fuel and backup fuel, and annual quantity of wastes burned.

Application for Air Contaminant Discharge Permit

2. Exhibit "B" - Plot Plan for the Air Contaminant Source Listed in Item 1.

Attach as Exhibit "B" a site plot plan showing the physical location of process equipment and air contaminant control equipment. Each air contaminant discharge point must be referenced with a unique descriptive item name identical to the item name used in Exhibit "A". The plot plan must show the location of the nearest residential and/or commercial property, structures, roadway, and clearly indicate proper site access.

Schedule III - Additional Plant Site Information

(SEE ATTACHMENTS)

1. Refuse Disposal Methods:

Indicate quantity of disposal, disposal method, and location of disposal for each type of residue, waste or refuse generated including liquid waste from air pollution control equipment.

- a. Material -
- b. Source -
- c. Quantity -
- d. Disposal Method -
- e. Disposal Site -

2. Other Air Contaminant Source(s):

Are other air contaminant source(s) located at plant site for which a permit is not being required at this time?

Yes ☐ No ☒ If yes, list each source and give a brief description:

- a. _____
- b. _____
- c. _____

3. Section 34-015 of the Lane Regional Air Pollution Authority Rules and Regulations makes provisions for the issuance of a "Special Letter Permit". If you are operating a facility with NO or INSIGNIFICANT air contaminant discharges, as determined by this Agency, a portion of the permit fees may be waived.

FINAL DETERMINATION OF APPLICABILITY FOR THE "SPECIAL LETTER PERMIT"
SHALL BE MADE SOLELY BY THIS AUTHORITY

If you feel a "Special Letter Permit" would be applicable for your facility, please sign:

Daniel J. [Signature]
(Signature of Owner or Legally Authorized Representative)
General Manager (Title) 2/14/90 (Date)

TABLE 1
GENSET ADDITION SCHEDULE

<u>Year</u>	<u>Addition</u>	<u>Project Total</u>	<u>Installed Capacity</u>
1990		3 gensets total	1800 kw
1992	1 additional genset	4 gensets total	2400 kw
1997	1 additional genset	5 gensets total	3000 kw
2000	1 additional genset	6 gensets total	3600 kw
2003	1 additional genset	7 gensets total	4200 kw

SCHEDULE II
DETAILED DESCRIPTION
OF AIR CONTAMINANT SOURCE

I. Exhibit A - Process Flow Diagram for the Air Contaminant Source (See page 12).

* Please note: All figures are listed for individual gensets (engines), not for project totals.

- A. Unique descriptive name of air contaminant discharge points:
 - 1. 7 engine exhaust stacks
 - 2. Potentially, 1 stand-by flare
- B. Description of material and quantity handled by control equipment:
 - 1. Note: This project has no post combustion - add-on control equipment for exhaust stack emissions.
 - 2. Exhaust stack emissions are:
 - a. nitrogen oxide - 15.3 tons/yr
 - b. carbon monoxide- 16.8 tons/yr
 - c. total hydrocarbons- 16.1 tons/yr
 - 1.) Non-methane hydrocarbons are estimated to make up 5 to 10 percent of these totals, on the average.
 - d. emission levels are based on an 85% availability factor
 - 3. Stand-by flare emissions are:
 - a. zero (0) emissions
- C. Air contaminant discharge point height above ground:
 - 1. 17'
- D. Muffler-air discharge outlet dimensions:
 - 1. muffler diameter - 16"
 - 2. muffler length - 72"
 - 3. muffler air discharge outlet diameter - 8"
- E. Air flow of engine combustion intake:
 - 1. 1440 cubic feet/minute
- F. Outlet dimension of control equipment:
 - 1. 8" diameter
 - 2. exhaust gas flow rate - 4030 cubic feet/minute
- G. Temperature of control equipment exhaust air:
 - 1. 1040 degrees Fahrenheit

H. Exhaust discharge orientation:

1. vertical

I. Fuel type and annual quantity of waste burned:

1. primary fuel type - landfill gas
 - a. annual quantity waste burned
 - 1.) fuel consumption/year - * see Table 2 - "Annual quantity of major material introduced into the process"
 - b. landfill gas - composition (volume percent)
 - 1.) oxygen - 2%
 - 2.) nitrogen - 6%
 - 3.) carbon dioxide - 36%
 - 4.) methane - 55%
- 2- fuel type backup - natural gas (potentially)

SITE PLAN

SHORT MOUNTAIN PROJECT

(Conceptual)

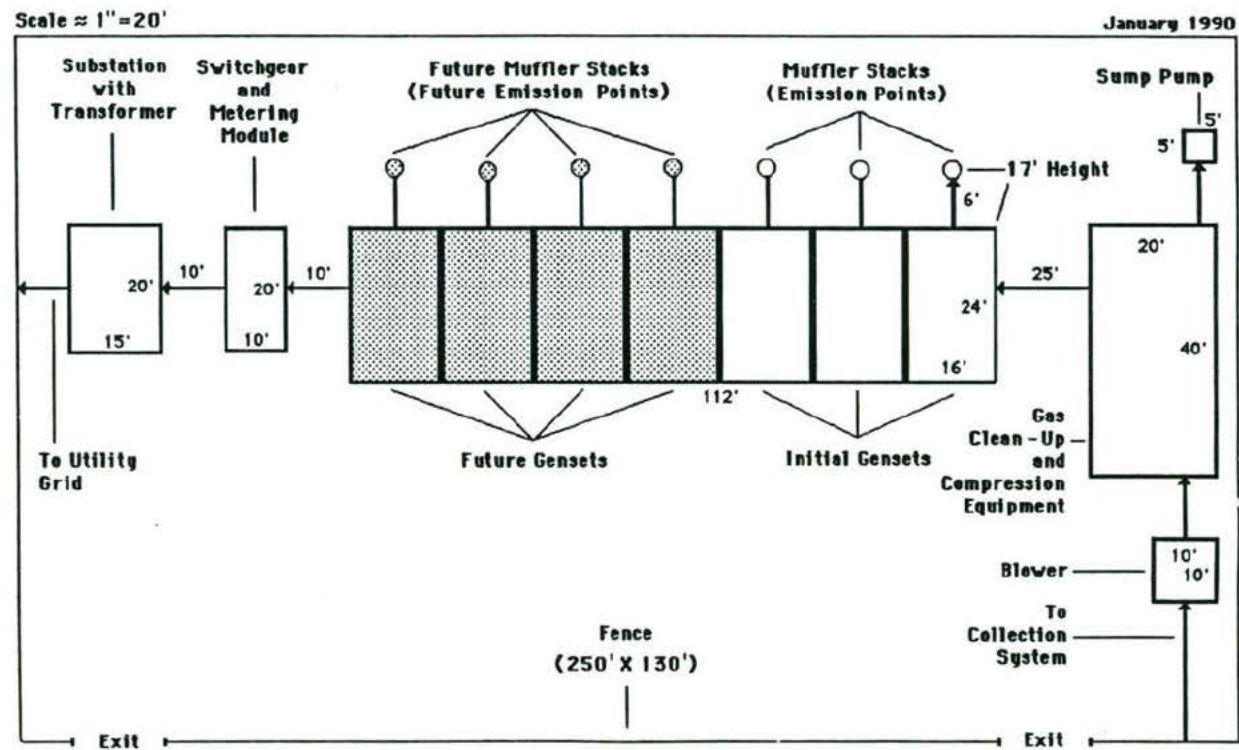
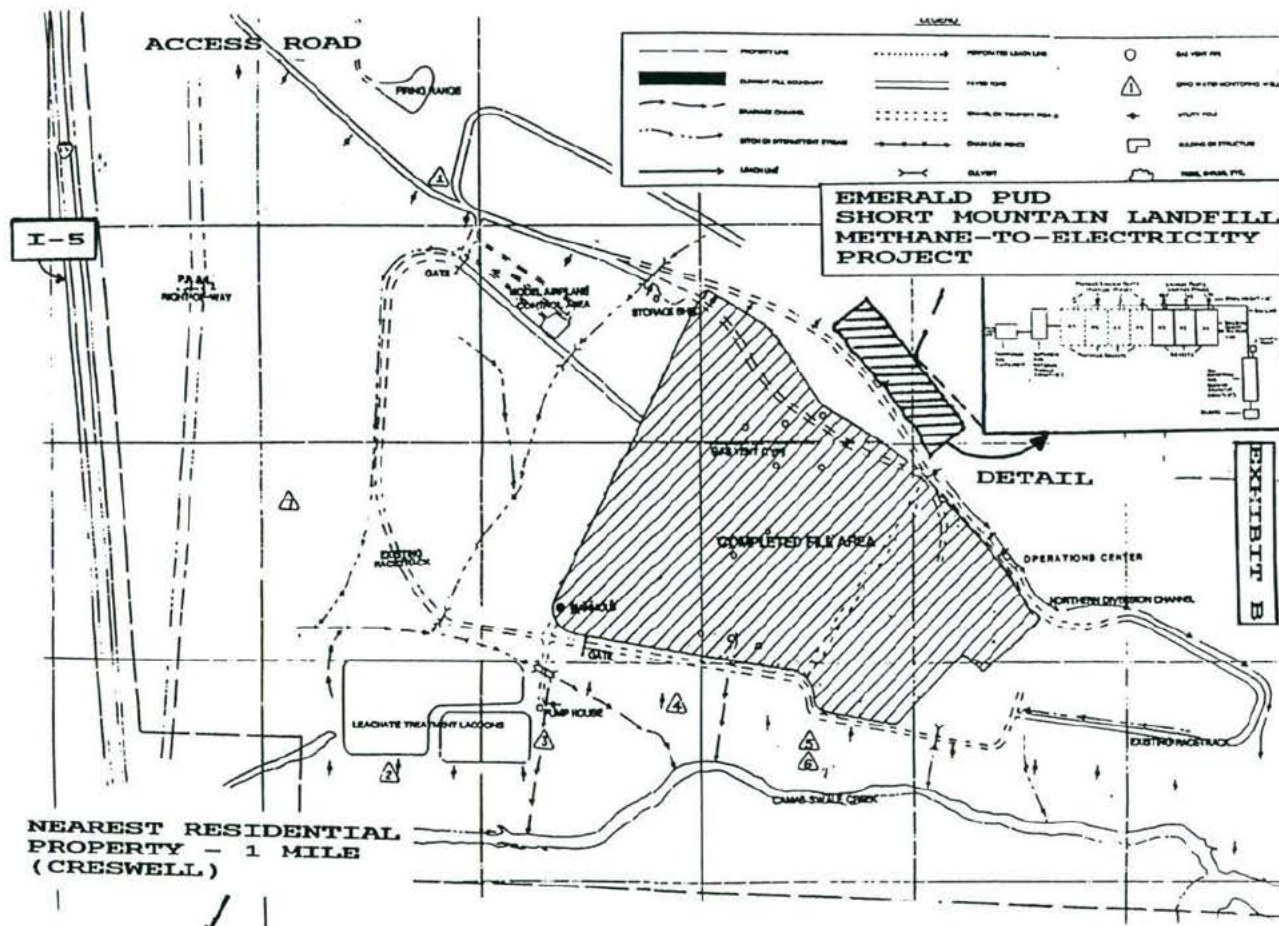


TABLE 2

Annual Quantity of Major material introduced into the process:
Schedule I - #2.b.

Material	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Recovered LFB (cubic feet per day)	1,225,900	1,293,500	1,363,700	1,438,450	1,517,100	1,598,350	1,684,800	1,773,850	1,867,450	1,965,600	2,068,300	2,176,850	2,291,250	2,410,200
Recovered Methane (cubic feet per day)	674,245	711,425	750,035	791,147	834,405	879,093	926,640	975,618	1,027,098	1,081,080	1,137,565	1,197,268	1,260,188	1,325,610
Recovered LFB (cubic feet per hour)	51,079	53,896	56,821	59,935	63,213	66,598	70,200	73,910	77,810	81,900	86,179	90,702	95,469	100,425
Recovered Methane (cubic feet per hour)	28,094	29,643	31,251	32,964	34,767	36,629	38,610	40,651	42,796	45,045	47,399	49,886	52,508	55,234
Recovered LFB (cubic feet per minute)	851	898	947	999	1,054	1,110	1,170	1,232	1,297	1,365	1,436	1,512	1,591	1,674
Recovered Methane (cubic feet per hour)	468	494	521	549	579	610	643	678	713	751	790	831	875	921

SCHEDULE IIEXHIBIT B"PLOT PLAN"



SCHEDULE IIIADDITIONAL PLANT SITE INFORMATION

1. Refuse Disposal Methods:

- a. Material - Condensate (The exact make-up of the condensate is not yet known, and will not be known until the project is built and the condensate is tested.
- b. Source - Landfill gas.
- c. Quantity - The exact quantity of the condensate is not yet known, and will not be known until the project is built and the condensate is tested.
- d. Disposal Method - Emerald is currently working with the Oregon Department of Environmental Quality to establish the disposal method for the condensate. Emerald will inform LRAPA when ODEQ makes a determination. At this point Emerald believes that the appropriate disposal method for the condensate is to pipe it into the existing leachate disposal system.
- e. Disposal Site - If the above disposal method is approved by the ODEQ all disposal will occur at the Short Mountain Landfill.

BACT ANALYSIS

BEST AVAILABLE CONTROL TECHNOLOGY

TOP-DOWN ANALYSIS

Emerald PUD has evaluated all of the available control options in Best Available Control Technology top-down analysis. It includes: a turbocharged low emission high compression engine, a stratified charge turbocharged engine, a turbocharged engine with a catalytic converter, and a turbocharged engine. Each of these control options is technologically feasible. However, while all of the control options are feasible and available, not all have been designated BACT. The catalytic converter option no longer is considered BACT in California for reasons discussed in this analysis. The stratified charge option, to the best of Emerald's knowledge, has not been designated BACT. In fact, the first test of this technology occurred in March of 1989 and only 10 options on the technology have been purchased. It is unclear how many, if any, stratified charge options are in actual operation. The low emission or "clean-burn" technology is considered BACT by the South Coast (Los Angeles) and the Bay Area (San Francisco) districts of California.

RANKING & DISCUSSION - BACT ANALYSIS

The top-down BACT effectiveness ranking of the emission control options, as determined by Emerald PUD, is as follows: 1.) turbocharged low emission high compression engine, 1.) (tied) stratified charge turbocharged engine, 3.) turbocharged engine with catalytic converter, and 4.) turbocharged engine.

While the stratified charge option has nominally lower emission rates than the low emission option, the rate in tons per horsepower for all three emissions is lower for the low emission engine option (see Appendix A - Emission Analysis Chart). Emerald has therefore decided to rank the low emission engine option and the stratified engine the same.

Pollution reduction attained by the emission control options is evaluated on the attached "Best Available Control Technology Analysis" chart. Emission rates in tons/yr, emission reduction in tons/yr, and control efficiency (% reduction) are presented for each emission control option. The emission rates listed for hydrocarbons represent total hydrocarbons, nonmethane hydrocarbons compose only 5-10% of the total hydrocarbon emissions. In 1990 dollars, the unit incremental costs, project incremental costs, and the economic impacts (\$/ton reduction) for each control option are presented for comparison. Footnotes explaining additional information pertinent to the BACT analysis are listed at the bottom of the chart for reference purposes.

Following the chart is a detailed discussion of the energy, environmental, and economic impacts of the various control technologies. Finishing this analysis is our justification for choosing the low emission engine option as the BACT for this project.

An important consideration in this decision is the fact that the site is outside the nonattainment area for CO and HC, and is not close enough to have an impact on that nonattainment area. NO_x is however approaching the standard near the site and is therefore of more concern.

Best Available Control Technology Analysis
Short Mountain Generation Project
Emerald People's Utility District

Control Alternatives		Turbocharged Engine (Baseline)	Turbocharged Engine w/ Catalytic Converter (1)	Stratified Turbocharged Engine (4)	Turbocharged Low Emission High Comp. Engine
Emission Rate (tons/yr)					
	NOx	144.5	29.5	14.3	15.3
	CO	10.7	2.3	14.3	16.1
	HC	6.1	na	14.3	16.8
Emission Reduction (tons/yr)					
	NOx	--	109.8	130.2	129.2
	CO	--	8.0	(3.6)	(5.4)
	HC	--	na	(8.2)	(10.8)
Control Efficiency (% reduction)					
	NOx	--	76.0%	90.1%	89.4%
	CO	--	75.0%	(33.8%)	(50.6%)
	HC	--	na	(135.1%)	(177.1%)
Unit Incremental Cost (\$1990)			(3)	(5)	(6)
		\$0	\$32,558	\$32,680	\$12,797
Project Incremental Cost (\$1990)		(2)			
		(\$1,116,500)	\$227,903	\$228,757	\$89,579
Annual Incremental Cost (\$1990)					
		\$0	\$17,558	\$9,680	\$0
Economic Impact (\$/ton reduced)					
	NOx	--	\$297	\$251	\$99
	CO	--	\$4,068	--	--
	HC	--	na	--	--

na = information not available

Data in parentheses indicates a net increase in emissions

Calculations based on an 85% availability factor, using Caterpillar G399.

- (1) Caterpillar literature states that a catalytic converter is incompatible with landfill gas.
- (2) Total capital cost for seven 600 kW Low Emission Caterpillar G399s
- (3) Catalytic converter costs include:
 - a. \$10,000 for the casing (one-time cost)
 - b. \$5,000 for the initial set of beads
 - c. \$15,000 for three additional bead changes per year
 - d. 4 hours downtime per month for bead washing:
 $[(4 \text{ hrs})(1,813 \text{ kWh/hr})(\$0.0156/\text{kWh})(12 \text{ months}) = \$1,358/\text{year}]$
 - e. 4 hours labor per month for bead washing:
 $[(4 \text{ hrs})(\$25/\text{hr})(12 \text{ months}) = \$1,200/\text{year}]$
- (4) Emissions from a smaller engine (870 hp) than the Turbocharged Low Emission engines (930 hp).
- (5) Cost to retrofit a turbocharged engine (\$23,000), and the cost of the associated 9% power loss due to the retrofit: $[(13,500,000 \text{ kWh per year}/3 \text{ units})(9\% \text{ power loss})(\$0.0239/\text{kWh}) = \$9,680/\text{year}]$
- (6) Additional capital cost to modify a standard turbocharged engine.

ENERGY IMPACTS - BACT ANALYSIS

- 1.) Low emission high compression ratio engine:
The use of this technology results in no significant or unusual energy penalties or benefits.
- 1.) Stratified charge engine:
The use of this technology results in a nine percent reduction in engine horsepower based on a comparison with the standard high compression turbocharged engine, and a corresponding nine percent reduction in kw output from the genset. This amounts to an energy loss of 1,215,000 kWh per year for the project, valued at approximately \$9700 per year (escalating with inflation).
- 3.) Turbocharged engine with catalytic converter:
Due to the required monthly change of beads, the gensets must be shut down for at least an extra four hours per month. These shut downs result in an energy loss of nearly 1% per year, over 82,000 kWh per year, valued at approximately \$1300 per year (escalating with inflation).
- 4.) Turbocharged engine:
The use of this technology results in no significant or unusual energy penalties or benefits.

SUMMARY

The turbocharged and low emission engine technologies have no energy penalty associated with their use. The catalytic converter technology has a modest energy penalty (1%), within the normal range for these technologies. However, the stratified charge technology option has a substantial energy penalty (9%) associated with its use, beyond the normal range for these technologies. For NO_x, the low emission engine has an "incremental energy cost" of 5.88 kW per ton of NO_x reduced, 16% better than the stratified charge engine incremental energy cost of 5.08 kW per ton of NO_x reduced. The catalytic converter option is 31.5% better (6.68 kW per ton of NO_x reduced) than the stratified charge engine and 13.6% better than the low emission engine.

ENVIRONMENTAL IMPACTS - BACT ANALYSIS

- 1.) Low emission-high compression ratio engine:
This technology poses no significant or unusual other media environmental impacts. There are no toxic or hazardous air contaminants associated with its use.
- 1.) Stratified charge engine:
This technology poses no significant or unusual other media environmental impacts. There are no toxic or hazardous air contaminants associated with its use.
- 3.) Turbocharged engine w/catalytic converter:
The internal beads from the catalytic converter must be washed on a monthly basis. Fluid used to wash the beads will contain traces of heavy metals and concentrations of the pollutants absorbed by the beads during operation. The beads must be replaced and disposed of every three months.

Disposal of the waste fluid from the monthly washing and disposal of the beads every three months will present a waste disposal environmental impact, with potentially substantial additional operating costs.

This technology poses no significant emission of toxic or hazardous air contaminants while in actual operation.
- 4.) Turbocharged engine:
This technology poses no significant or unusual environmental impacts. There are no toxic or hazardous air contaminants associated with its use.

SUMMARY

From the project flow chart on page 3, one can see that each of these technology options are add-ons to the engine/generator sets succeeding the gas clean-up and compression equipment. None of these technologies, therefore, will have any impact on the quantity or quality of the condensate discharged from the gas clean-up equipment and compression equipment.

Only the catalytic converter technology option has significant or unusual other media environmental impacts.

ECONOMIC IMPACTS - BACT ANALYSIS

- 1.) Low emission high compression ratio engine:
This technology option has the lowest unit incremental cost at \$12,797, the lowest project incremental cost at \$89,579, and no annual incremental cost. The economic impact expressed as dollars per ton of NO_x reduced is also the lowest at \$99. Our economic analysis indicates that the project is still economic when adding this option to the turbocharged engines.
- 1.) Stratified charge engine:
The unit incremental cost for this option is \$32,680, the project incremental cost is \$228,757, and the annual cost per unit is \$9680. The economic impact is \$251 per ton of NO_x reduced.
- 3.) Turbocharged engine w/catalytic converter:
The unit incremental cost for this option is \$32,558, the project incremental cost is \$227,903, and the annual cost per unit is \$17,558. The economic impact is \$297 per ton of NO_x reduced.

SUMMARY

The incremental cost of the catalytic converter option is over 2.5 times that of the low emission engine with less of a reduction in NO_x emissions (76% versus 89.4%), but more of a reduction in CO. The cost per ton of NO_x reduced is three times greater than the low emission engine, and the annual cost per unit is substantially higher. This technology is no longer BACT in California partly because of the substantial cost difference with low emission engines.

The incremental cost and the cost per ton of NO_x reduced for the stratified charge option is also over 2.5 times that of the low emission engine option, with the reduction in tons of NO_x nearly equal. The increase in CO is 42% less than that from the low emission engine, and the hydrocarbon increase is 18% less. The project incremental cost is also 2.5 times that of the low emission engine, and the annual incremental cost is substantial to the project. Since the emission reductions and increases for the stratified charge option is nearly the same as the low emission engine option, we consider the cost for the stratified charge option to be "disproportionately high", as compared to the low emission engine option.

Additionally, the unusual factor of extraordinarily low avoided energy cost in the Pacific Northwest compared to California (two and one-half times lower) must be taken into consideration. The incremental cost of the stratified charge option makes the project much less economic and would put the project's viability in question. The higher avoided energy cost in California allows much more expensive control technology options without impacting the economic viability of a project.

BACT JUSTIFICATION

Emerald PUD proposes the low emission engine technology as Best Available Control Technology (BACT) option for the Short Mountain Methane-to-Electricity Project. This technology is now recognized as BACT in the South Coast (Los Angeles) and Bay Area (San Francisco) Air Quality Districts of California, and it should be noted that the air quality in the Eugene area is markedly better than in either of those Air Quality Districts.

The air quality modeling done by BWR Associates of Medford, Oregon also indicates that the project with low emission engines will not exceed the National Ambient Air Quality Standards.

Moreover, by developing this project as described the odor and greenhouse gases (carbon dioxide and methane) escaping from the landfill will be nearly eliminated. We estimate a reduction in 1991 of nearly 400 million cubic feet per year of methane and 260 million cubic feet per year of carbon dioxide. This amount would more than double by the year 2007 when the landfill's gas production peaks.

The low emission engine technology option offers the best overall combination of energy output and exhaust emission reduction when compared to the stratified charge or the catalytic converter technology options. Catalytic converters entail a 1% penalty in energy, primarily due to the monthly downtime for changing the converter beads. The stratified charge technology has a substantial 9% energy penalty when compared to low emission technology: beyond the normal range for these technologies. While the low emission technology option reduces nearly the same amount of emissions as the stratified charge technology option, the low emission technology option offers a 16% advantage over the stratified charge option in the incremental energy cost of reducing NO_x emissions.

The low emission technology option poses no significant or unusual other media environmental impacts, but the use of catalytic converters poses significant environmental and disposal problems associated with the monthly cleaning and quarterly disposal of the converter's internal beads. Caterpillar literature also states that catalytic converters are not compatible with a landfill gas operation (see Appendix B - August 17, 1989 article, page 1).

The low emission engine technology option is also significantly more economic in terms of cost per ton of NO_x removed from exhaust emissions (\$99/ton as opposed to \$251/ton for the stratified charge technology and \$299/ton for catalytic converter

technology). Due to the substantial cost differential between the low emission technology and catalytic converters, as well as the additional environmental impacts and impact on engine performance, catalytic converters are no longer recognized as BACT in California. The stratified charge technology option offers unsubstantial reductions in levels of NO_x emissions at a disproportionately high cost as opposed to the low emission engines. Requiring the stratified charge technology option would put the economic viability of the project in jeopardy.

Finally, because the stratified charge technology is relatively new and in our view unproven, it should not be designated as BACT.

In summary, the low emission technology option offers the best combination of emission reduction levels, energy impacts, environmental impacts, and economic impacts. National Ambient Air Quality Standards will also be met using this technology option on the project. Emerald PUD therefore feels that there is considerable justification for designating the low emission technology option as the Best Available Control Technology for the Short Mountain Project. The low emission engine technology would allow the Short Mountain Project to produce its significant benefits for the area while maintaining the air quality of the region.

APPENDIX AEMISSIONS CALCULATION TABLE USED TO CREATE
THE BACT ANALYSIS CHART

EMISSION ANALYSIS - CATERPILLAR G399 & G398

Emissions per Genset					Total for 7 Gensets			Ton/Horsepower		
Genset	HP	NOx (Tons/Yr)	HC (Tons/Yr)	CO (Tons/Yr)	NOx (Tons/Yr)	HC (Tons/Yr)	CO (Tons/Yr)	NOx (Ton/HP)	HC (Ton/HP)	CO (Ton/HP)
STANDARD ENGINES:										
399 HC-TA	915	144.5	6.1	10.7	1011.2	42.5	74.7	0.158	0.007	0.012
399 LC-TA	803	129.4	4.8	9.5	906.1	33.3	66.6	0.161	0.006	0.012
398 HC-TA	713	88.6	4.1	7.4	620.5	28.7	51.7	0.124	0.006	0.010
398 LC-TA	640	NA	NA	NA	NA	NA	NA	NA	NA	NA
LOW EMISSION ENGINES:										
399 HC-TA	930	15.3	16.8	16.1	106.9	117.8	112.5	0.016	0.018	0.017
399 HC-TA	830	13.6	15.0	14.4	95.4	105.3	100.6	0.016	0.018	0.017
398 HC-TA	700	11.9	10.0	8.5	83.3	70.2	59.5	0.017	0.014	0.012
398 HC-TA	625	9.0	9.2	7.4	62.8	64.3	51.8	0.014	0.015	0.012
STRATIFIED CHARGE										
399 HC-TA	870	14.3	14.3	14.3	100.0	100.0	100.0	0.019	0.019	0.019

Calculations in this table are based on an 85% availability factor.

Calculation Table for Emissions

Genset	HP	NOx (g/h)	NOx (g/hp-h)	NOx (Tons/Yr)	HC (g/h)	HC (g/hp-h)	HC (Tons/Yr)	CO (g/h)	CO (g/hp-h)	CO (Tons/Yr)	AIR-FUEL (m3/m3)	Percent O2
STANDARD ENGINES												
399 HC-TA	915	17600	19.2	170.0	740	0.8	7.1	1300	1.4	12.6	10.4	2.0%
399 LC-TA	803	15770	19.6	152.3	580	0.7	5.6	1160	1.4	11.2	10.4	2.0%
398 HC-TA	713	10800	15.1	104.3	500	0.7	4.8	900	1.3	8.7	10.1	2.0%
398 LC-TA	640	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
399 HC-NA	653	17556	26.9	169.5	290	0.4	2.8	528	0.8	5.1	10.9	2.0%
399 LC-NA	591	15960	27.0	154.1	900	1.5	8.7	480	0.8	4.6	10.6	2.0%
398 HC-NA	499	10850	21.7	104.8	750	1.5	7.2	1000	2.0	9.7	10.0	2.0%
LOW EMISSION ENGINES												
399 HC-TA	930		2.0	18.0		2.2	19.8		2.1	18.9		
399 HC-TA	830		2.0	16.0		2.2	17.7		2.1	16.9		
398 HC-TA	700		2.1	14.0		1.7	11.8		1.5	10.0		
398 HC-TA	625		1.8	10.6		1.8	10.8		1.4	8.7		
STRATIFIED CHARGE												
399 HC-TA	870		2.0	16.8		2.0	16.8		2.0	16.8		

Calculations in this table are base on a 100% availability factors.

HC = High Compression Ratio
 LC = Low Compression Ratio
 TA = Turbocharged
 (Source: Pape CAT, Eugene, OR, 1-10-90)

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O.R.S. § 340-31.

42 U.S.C.A. §§ 7401 - 7462.