Report

Updated Research Report on Bioreactor Landfills, Landfill Leachate Recirculation and Landfills with Methane Recovery

Scope I.D.: 04R004

Ramsey/Washington County Resource Recovery Project

September 2004

Updated Research Report on Bioreactor Landfills, Landfill Leachate Recirculation and Landfills with Methane Recovery

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Prepared for

Ramsey/Washington County Resource Recovery Project

1670 Beam Avenue, Suite A
Maplewood, Minnesota 55109-1129

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September 2004

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Executive Summary

Introduction

The Ramsey/Washington County Resource Recovery Project Board (Board) has a service agreement with NRG Energy, Inc. (NRG) to process solid waste from the two counties at the Newport Resource Recovery Facility (Facility). The agreement provided that Northern States Power Company (NSP), the predecessor to NRG, design, construct, and operate the Facility. The Facility began processing solid waste into refuse-derived fuel (RDF) in 1987 and the service agreement extends until 2007.

In 2000, as part of the preliminary planning process for waste management options after the end of the current service agreement, the Board initiated a research study to see what other solid waste processing technologies might have potential merit besides a continuation of the service agreement with NRG to process municipal solid waste (MSW) into RDF. Bioreactor landfills with recovery technology was identified by the Board to be included in that research.

In 2004, the Board requested updates to the original report. This report updates the bioreactor landfill technology plus adds sections on leachate recirculation and methane recovery from landfills.

The purpose of this report is to help inform policy makers on the status of these three technologies. The report describes each technology, how it may apply to Ramsey/Washingotn counties, and potential advantages and disadvantages. While leachate recirculation and methane recovery are addressed separately, it is important to note that leachate recirculation and methane recovery are both part of the bioreactor landfill technology.

Bioreactor Landfills

The term “bioreactor” when used in relation to landfill practices is not well defined throughout the solid waste industry. For example, the USEPA National Emissions Standards for Hazardous Air Pollutants (40CFR 63, subpart AAAA) defines a bioreactor landfill as liquids being added to the waste mass to achieve a minimum of 40 percent by weight moisture in anaerobic conditions. The Solid Waste Association of North America (SWANA) defines bioreactor landfills as “a controlled landfill or landfill cell where liquid and gas conditions are actively managed in order to accelerate or enhance biostabilization of the waste.” Furthermore, some solid waste professionals use the term “bioreactor” and “leachate recirculation” interchangeably. To reduce confusion, this report defines a bioreactor landfill as a landfill that injects liquids other than (or in addition to) leachate and gas condensate in a controlled manner into the waste mass. The bioreactor may be aerobic (with oxygen) or anaerobic (without oxygen).

The goals of bioreactor landfills typically are to:

Speed waste stabilization
Enhance gas production
Increase available landfill airspace
Improve leachate storage and treatment; thereby reducing leachate management costs
Reduce the length and cost of post-closure activities

In a bioreactor landfill, during a period of several years, degradable organic wastes are converted to a soil-like humus through the addition of liquids to landfilled waste. The degradation of waste causes settlement to occur. This rapid settlement can then be used as airspace. The increase in airspace is estimated to be 20 percent or more of the waste depth at bioreactor landfills as a result of settlement compard to 8 to 12 percent for traditional landfills. However, with bioreactor landfills, the settlement occurs during operations rather than during post-closure as at traditional "dry tomb" landfills and the airspace can be captured and utilized. This could be viewed as comparable to a waste diversion program diverting 20 percent of the waste from the landfill. Reusing the airspace also increases revenues since more waste goes into the same space.

Table ES-1 summarizes several potential advantages and disadvantages of bioreactor landfills

Table ES-1 Potential Advantages and Disadvantages of Bioreactor Landfills

Advantages	**Disadvantages**
More rapid waste stabilization	Not fully proven technology as yet
Minimize long-term environmental liability	Potential for increased odors
Potential reduced post-closure time period	Increased potential for slope stability problems
Increased airspace caused by settlement that may minimize need for siting new landfills	Higher capital and operating costs than sanitary landfills
Enhanced gas production with potential energy recovery revenues	Bioreactor technology is not currently being considered as a full-scale technology by the Minnesota Pollution Control Agency (MPCA)
Improved leachate storage and treatment at lower costs	
Reduced leachate toxicity	
Does not compete with recycling and composting programs.	

Advantages/Disadvantages

Primary advantages appear to be the more rapid waste stabilization resulting in reductions in the long-term risk of groundwater contamination and reduction in leachate toxicity. This reduces the long-term potential liability associated with the current dry tomb landfill technology. In addition, leachate treatment costs are reduced or eliminated due to the recirculation aspect of the bioreactor. The ability to reuse the airspace gained from waste settlement in bioreactor landfills may also reduce the total land area required to host new or expanded landfills, which seems consistent with Minnesota= s proposed long term solid waste policy[1]. Bioreactor landfills can also be a positive component of an integrated waste management system wherein organics are targeted for source-separated composting.

However, at this point, bioreactor landfills are only permitted using site-specific rule variances from the USEPA. The EPA issued the final rule on Research, Development and Demonstration Permits for Municipal Solid Waste Landfills (FR Vol. 65, No. 55, March 22, 2004) that gives approved states authority to issue permits for bioreactor projects. The rules require states to adopt regulations (subject to EPA approval) to issue RD&D permits. MPCA has received authority from EPA for RD&D type projects (69 FR 54756); however, Solid Waste staff at the MPCA have indicated permitting bioreactor technology is not a priority for the MPCA at this time.

Discussions with local waste disposal companies indicated they are very interested in bioreactor landfill technology implementation. Waste Management, Inc. (WMI)indicated they believe bioreactor landfills could be permitted in Iowa in as soon as 24 months. BFI indicated they believe they could develop a bioreactor landfill in Wisconsin. Both companies indicated that they would be interested in pursuing regulatory approval in Minnesota[2].

Costs for bioreactor landfills are comparable to current landfill disposal costs. The increased costs for capital facilities to re-introduce liquids into the waste and increased operating costs of a bioreactor landfill are offset by increased waste capacity in a bioreactor landfill and potentially reduced post-closure time period due to waste stabilization in a bioreactor landfill. These offsets and the increased benefits of more methane production (a potential revenue source) and the ability to re-introduce other liquids (like industrial sludges, another revenue source) into the waste mass for treatment makes the economics for bioreactor landfills attractive to private disposal companies.

Bioreactor landfills also compliment existing recycling and composting programs. Bioreactor landfills advantages (rapid waste stabilization, reduced leachate toxicity and increased settlement) are neither enhanced nor reduced by aggressive recycling and/or composting programs. The reality is, organic materials will continue to be placed in MSW landfills. Bioreactor technology stabilizes these organics to reduce the long-term risk of pollution.

Bioreactor landfill technology is in the advanced research and development stage and is not currently allowed by the MPCAAlthough it is not fully proven at full -scale size, this should change in the next few years with new federal rules allowing states to develop bioreactor technologies using the RD&D rule and current projects underway that should further support the development of full-scale bioreactor landfills.

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[1] Minnesota Office of Environmental Assistance, *Solid Waste Policy Report* "Waste Management in Minnesota: A transition to the 21st century," January 2000.

[2] Conversations with Waste Management, Inc. staff, June 29, 2004, and BFI staff on June 30, 2004.

Observations

Despite the potential disadvantages, the bioreactor landfill technology appears to offer some significant long-term advantages. The rapid waste stabilization and reduced long-term liability aspects provide a significant potential advantage over dry-tomb landfills. Furthermore, studies indicate bioreactor landfills offer less environmental impact than conventional landfills.

Bioreactor landfill technology can easily be combined with other technologies and/or the technology could be fully compatible with current recycling, source-separated organics recovery, and waste-to-energy facilities.

Leachate Recirculation

Leachate recirculation differs only from bioreactor landfill technology by the source of the recirculated liquid. Bioreactors typically add additional liquid, other than leachate or gas condensate, to bring the waste to a moisture content of 40 percent. Leachate recirculation landfills only recirculate leachate (and gas condensate) produced at the landfill. This tends to limit the ability to achieve a waste moisture content of 40 percent, except in wet climates such as in the eastern and southeastern United States.

The process for leachate recirculation is the same as bioreactor landfills. Thus, the goals of rapid waste stabilization, enhanced gas production, increased landfill space, improved leachate management and reduced post-closure time and costs are true for leachate recirculation landfills. However, the magnitude of the goals is limited compared to bioreactor landfills since recirculated liquids are limited.

Landfills with leachate recirculation are becoming more common and a good database is being developed on the performance of leachate recirculation landfills. The Solid Waste Association of North America (SWANA) reports 36 leachate recirculation projects are ongoing in North America. In Minnesota, the MPCA has received nine applications for pilot leachate recirculation projects. As of this report, three projects are actively recirculating leachate in Minnesota.

Advantages and Disadvantages

Potential advantages and disadvantages for leachate recirculation are much like bioreactor landfills, except full-scale leachate recirculation is permitted by current rules in neighboring states. Thus, this technology could currently be utilized by Ramsey/Washington counties at an out-of-state facility. WMI, BFI, and Onyx have landfills in other states employing leachate recirculation. The magnitude of the advantages (e.g., increased settlement) and disadvantages (e.g., odors) is not as great as bioreactor landfill technology. However, leachate recirculation is a more developed technology than bioreactor landfills; making implementation, operations and engineering less burdensome than with bioreactor landfill technology.

Observations

For Ramsey/Washington counties, the "wait and see" position of the MPCA will limit the expansion of leachate recirculation to full-scale projects in Minnesota for the next several years. The MPCA's approach to permit limited pilot projects with considerable data gathering, reporting and permitting can be a deterrent for all but large landfills to pursue further leachate recirculation projects. Currently, for Ramsey/Washington counties to implement this technology on a full scale basis, an out-of-state landfill would need to be identified. Adjacent states are less restrictive in permitting large-scale leachate recirculation landfills and private disposal companies have existing programs in place at out-of-state landfills.

Landfills with Methane Recovery

Landfills with methane recovery are common in the United States where large waste quantities generate significant amounts of landfill gas (LFG). LFG is the by-product of the breakdown of organic material in a landfill, usually in anaerobic conditions. LFG contains methane, carbon dioxide and trace contaminants. LFG can either be vented to the atmosphere (typical at small landfills) or collected using an active gas collection system. An active gas collection system consists of wells, a blower to apply suction to the wells, and a control device (e.g., flare, engine, turbine, etc.). Federal air quality regulations require active LFG collection at landfills with capacities greater than 2.76 million tons, or 3.27 million cubic yards.

LFG, when actively collected, can be used to generate electricity, heat or both. By far, the largest use of LFG in the United States is for electrical generation. The U.S. Environmental Protection Agency's Landfill Methane Outreach Program (LMOP) reports 273 separate projects to convert LFG into electricity. Minnesota has four such projects at WMI-Burnsville, WMI-Elk River, BFI-Flying Cloud and BFI-Pine Bend landfills. Other uses for LFG include direct use (e.g., heat source for boilers), cogeneration (both electricity and thermal uses) and specialty uses (fuel for vehicles).

Advantages/Disadvantages

For Ramsey/Washington counties, LFG recovery is not a stand alone option. A landfill would need to be developed and 2 to 3 million tons in place before methane recovery would become an option. The LFG conversion method selected would depend on the location of the landfill, potential adjacent LFG users, and power grid connection locations. Assuming a landfill site is identified and developed, the advantages of methane recovery would be limiting greenhouse gas emissions and generating "green power." However, the current lack of tax incentives to develop LFG to energy projects makes LFG conversion technologies costly.

Observations

LFG technologies for collection and conversion are well developed and can easily be installed at most landfill sites. The lack of tax credits makes independent developers of LFG projects less aggressive. Federal regulations requiring active LFG collection and control at larger landfills would require Ramsey/Washington counties to install LFG collection soon after initial landfilling. This would provide the opportunity to employ LFG conversion technologies, but may not be cost effective. Profitability of such a project would be enhanced with bioreactor or leachate recirculation technology used at the landfill.

Conclusions

For Ramsey/Washington counties' waste stream, each technology has significant advantages. However, at this time, implementing bioreactor landfill or leachate recirculation technology would require disposal of MSW at landfills located out of state. The current regulatory climate in Minnesota does not support full-scale bioreactor landfill or leachate recirculation projects in the near or medium term (next several years). This could change (i.e., happen quicker) with an external (non-MPCA) push by companies and public entities interested in the technology. Some potential candidate sites in neighboring states may provide the opportunity to develop these technologies for Ramsey/Washington countiesmore quickly or on a pilot basis . Both WMI and BFI expressed interest in utilizing Ramsey/Washington counties' waste in a bioreactor landfill or leachate recirculation landfill with methane recovery.

Methane recovery from landfills has numerous benefits. The Ramsey/Washington counties' waste stream quantity and quality would support LFG conversion technologies. LFG production would only be enhanced with implementation of bioreactor landfill or leachate recirculation technologies. But, methane recovery is not a stand-alone technology and would require either siting a landfill or obtaining landfill space at an existing facility with the ability to take advantage of LFG conversion technologies. Most large sites, as would be required for the Ramsey/Washington counties waste stream, have methane recoverywith conversion. This could be further enhanced if federal tax credits become available in the future.

This report was developed to help educate policy makers on these three technologies and how these technologies could be applied to Ramsey/Washington counties. To a certain extent, the technologies are a "subset" of the previous technologies (i.e., bioreactor landfills would include both leachate recirculation and methane recovery). Each of the technologies include all the inherent engineering, operational, and financial assurance features of modern sanitary landfills, which are fundamentally different from the early landfills found to contaminate groundwater. But beyond this, bioreactor landfills have the potential to:

- Speed the decomposition process of the wastes such that the generation of leachate and landfill gas occurs sooner rather than being delayed until some time longer in the future when liners and covers have had more time to fail.
- Significantly reduce potential long-term environmental consequences of landfilled wastes.
- Save landfill space.
- Improve leachate treatment and actually reduce the toxicity of the leachate.
- Enhance landfill gas production so that it can be more effectively recovered and utilized beneficially.
- Reduce the length and cost of post-closure activities.
- Cost no more per ton than current Subtitle D landfills ($20 to $30 per ton).

Ramsey/Washington counties’ officials should learn more about these technologies, how they differ from early landfills, and how a bioreactor landfill could fit into future solid waste management practices. Activities to increase familiarity with the bioreactor landfill technology could include discussions with professionals active in the industry and site visits to existing facilities. Ramsey/Washington counties can then consider the potential advantages and disadvantages of bioreactor landfills along with other available options for managing solid wastes. Bioreactor landfill technology could be fully compatible with current recycling, source-separated organics recovery, and existing waste-to-energy facilities. Bioreactor landfills is an emerging technology that some day could be used to manage MSW not handled higher on the waste management hierarchy.

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Landfills with Methane Recovery

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1. Introduction

This report is a research study on bioreactor landfills, landfills that recirculate leachate, and landfills with methane recovery and the applicability of these technologies to Ramsey/ Washington counties. The purpose of the report is to inform policy makers about these technologies for consideration in the overall solid waste master planning process conducted in the region.

Bioreactor landfills are distinguished from landfills that recirculate leachate by defining bioreactors as landfill cells that recirculate other liquids in addition to leachate and gas condensate. This distinction is also necessary from a regulatory perspective. Returning leachate and condensate to Subtitle D designed landfills is a generally accepted practice and allowed by regulations[1]. The addition of other liquids (other than leachate and condensate) into a Subtitle D landfill cell is only allowed if the United States Environmental Protection Agency (USEPA) issues a site-specific permit. This could change in the near future with the current Research, Development and Demonstration (RD&D) rule issued by the USEPA[2]. The RD&D rule allows states to develop rules for permitting bioreactor landfills and alternative closure caps.

The report is assembled by first discussing the current technology, followed by current uses of the technology; applicability of the technology to the waste stream; permitting and regulatory issues; a discussion of existing facilities using the technology; and the applicability of the technology to Ramsey/Washington counties. Since there is similarity between bioreactor landfills and leachate recirculation, some sections may be duplicated; however, each technology has a separate section. It should be noted that leachate recirculation and methane recovery are practices inherently conducted at a bioreactor landfill.

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[1] MSW Landfill Criteria Technical Manual Subpart C, United States Environmental Protection Agency. EPA 530-R-93-017, pp.108.

[2] Code of Federal Regulation, Chapter 40, Section 258.28.

2. Bioreactors

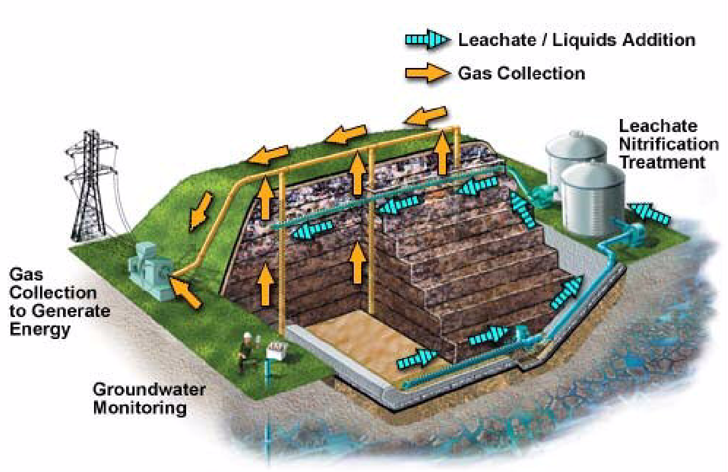
2.1 Technology Description

2.1.1 Overview

The term “bioreactor” when used in relation to landfill practices is not well defined throughout the solid waste industry. For example, the USEPA National Emissions Standards for Hazardous Air Pollutants (40CFR 63, subpart AAAA) defines a bioreactor landfill as liquids being added to the waste mass to achieve a minimum of 40 percent by weight moisture in anaerobic conditions. The Solid Waste Association of North America (SWANA) defines bioreactor landfills as “a controlled landfill or landfill cell where liquid and gas conditions are actively managed in order to accelerate or enhance biostabilization of the waste.” Furthermore, some solid waste professionals use the term “bioreactor” and “leachate recirculation” interchangeably. To reduce confusion, this report defines a bioreactor landfill as a landfill that injects liquids other than (or in addition to) leachate and gas condensate in a controlled manner into the waste mass. The bioreactor may be aerobic (with oxygen) or anaerobic (without oxygen). Further details of bioreactor landfills follow.

In general, the bioreactor landfill utilizes one of three operational processes:

Aerobic – An aerobic bioreactor collects leachate from the bottom of the waste and is typically stored. From storage, leachate is re-injected back into the waste mass (possibly with other liquids) in a controlled manner. Air is also injected into the waste mass using vertical and/or horizontal wells. The goal is to optimize oxygen and moisture content of the waste. Aerobic biological decay produces carbon dioxide and small amounts of ammonia.



Anaerobic – An anaerobic bioreactor collects leachate from the waste for re-injection with additional liquids. The goal is to optimize the moisture content of the waste mass. Biological activity occurs in the absence of oxygen (anaerobically). This biological activity produces methane and carbon dioxide that is captured to minimize greenhouse gas emission and for energy recovery.

Hybrid – A hybrid bioreactor utilizes techniques of both the aerobic and anaerobic processes. A sequential aerobic-anaerobic operation is used to rapidly degrade and stabilize the waste. Leachate is collected from the landfill and recirculated with other liquids back into the waste mass. The injection of air into the waste is sequenced based on internal parameters, primarily waste mass temperature. Aerobic-Anaerobic decomposition produces methane and carbon dioxide. These gases are captured to minimize greenhouse gas emissions and for energy projects.

The goals of bioreactor landfills typically are to:

Speed waste stabilization
Enhance gas production
Increase available landfill airspace
Improve leachate storage and treatment
Reduce the length and cost of post-closure activities

Bioreactor landfills “with recovery” go one additional step and incorporate a planned landfill excavation or reclamation phase with the intention of removing degraded and inert waste and reusing each bioreactor cell at the end of a period of time. This is done to accommodate an additional goal of minimizing the total amount of land area that must be permanently dedicated to landfilling.

During a period of several years, degradable organic wastes are converted to a soil-like humus through the addition of liquids to landfilled waste. In bioreactors “with recovery,” at the end of the decomposition period, the degraded waste is excavated (mined), screened, and any remaining inorganic waste residue landfilled. Research conducted throughout the United States indicates that ultimate diversion of waste from land-based disposal may reach as high as 50 to 80 percent when landfilling excavation (i.e., the recovery phase) is included as a planned component of the bioreactor process.

2.1.2 Detail

A bioreactor landfill is a landfill cell constructed with a composite bottom liner and a leachate collection system, much like a traditional landfill cell. However, t he construction differs from that of a traditional “dry tomb” landfill. The following paragraphs detail the differences between dry tomb landfills and bioreactor landfills.

A system to allow liquids (and air if aerobic) to be added to the waste during filling and again during operation. The optimum moisture content for waste degradation is reported to be 60 to 70 percent.[3] (Note: the USEPA defines bioreactor as a landfill that

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[3] E&A Environmental Consultants, ABluestem Solid Waste Agency Bioreactor Cell Pilot Project Operating Protocol and Monitoring Plan Draft Report,≅ August 1997.

achieves 40 percent, by weight, moisture content by adding liquids[4].) The amount of liquid needed to be added to achieve optimum moisture and the potential for evaporative loss makes bioreactor cells in all but high rainfall areas likely to dry out if the only liquid used is naturally occurring leachate. However, in some parts of the country, primarily in the East and Southeast sufficient liquid from leachate may achieve optimum moisture if only leachate recirculation is conducted. Thus, optimum moisture may be achieved without adding additional liquid. Adding liquids back into the waste requires an enhanced leachate collection system for effective operations.

Liquid recirculation systems to allow moisture levels to be maintained and regulated throughout the decomposition process. Recirculation systems can be either vertical, horizontal, spray or a combination. Vertical systems usually consist of large diameter wells drilled into the waste. Liquid is injected into the wells and allowed to percolate into the waste. The advantage of the vertical system is large amounts of liquid can be recirculated. However, some studies have indicated the waste adjacent to the vertical recirculation wells tends to become over-saturated and inhibits distribution of the recirculated liquids. Thus, vertical recirculation systems have a short life and limited influence area. There is also concern about the vertical well “short circuiting” recirculated liquid into the leachate collection system; thus, reducing effectiveness of the system.

Horizontal recirulation systems consist of horizontal pipes in trenches at predetermined depths in the waste. Trenches are typically filled with porous materials like aggregate or tire chips. The liquids are pumped to the trenches from a holding pond or tank or the trenches are filled manually by trucking the liquid to the recirculation pipes and gravity feeding the liquid to the pipes. Pressure injection applications have also been installed where liquid is injected under high pressure into the waste mass. Horizontal systems have not exhibited over saturation characteristics that vertical systems have. Horizontal systems tend to have a longer life than the vertical system but are subject to settlement induced damage. Horizontal systems also require more accurate liquid monitoring and recirculation strategies. Monitoring liquids recirculation in horizontal recirculation systems is critical to preventing recirculation induced environmental problems like leachate seeps and liquid induced slope instability.

Spray recirculation systems typically use trucks to transport liquids from holding areas to the working face. Waste is sprayed with liquid prior to and during compaction. This liquid application process has demonstrated a great ability to saturate the waste and provide good distribution of liquids throughout the waste mass. However, odor, aesthetics and worker/customer health and safety issues tend to mitigate the benefits of this application process. Thus, spray application of liquids is not highly used in current bioreactors. However, in particularly dry areas where significant quantities of make up water are needed to bring the waste to proper moisture content, a spray system using water, coupled with a horizontal or vertical system for leachate recirculation can be effective.

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[4] USEPA – National Emission Standards for Hazardous Air Pollutants, 40 CFR63, Subpart AAAA.

Thicker than standard protective layer and drainage layer between the cell liner and MSW to minimize liner damage. This feature is essential for bioreactors with recovery. However, most bioreactor landfills have enhanced leachate collection systems to handle the increased liquids loading due to recirculation. Some researchers are also recommending the use of washed drainage stone rather than sand as the media above the cell liner. Drainage stone offers better permeability and is less susceptible to biological clogging. Increasing the slope of the leachate system and cell floor is also used to ensure acceptable leachate collection.

Enhanced gas recovery systems. The accelerated decomposition process of aerobic, anaerobic and hybrid bioreactors speeds landfill gas generation. Peak gas production is reached rapidly and gas generation is compressed to a shorter time than conventional landfills. This requires an enhanced gas collection and control system to capture the landfill gas. The gas collection system can be either horizontal or vertical wells placed in the waste. The wells are typically slotted pipes in a bed of aggregate materials. Horizontal systems offer the ability to be installed as part of operations and can be activated sooner to increase landfill gas capture efficiency. Vertical systems are well studied as to performance, operation and maintenance. Thus, they are common. However, installation requires a drilling rig and a vertical well is difficult to extend when future waste is placed. Furthermore, collection header routing in a vertical well system needs considerable planning prior to construction to avoid damage to the headers. Vertical systems are common on closed landfills.

Odor control measures. Odor is reported to be more of an issue with a bioreactor landfill than with a conventional landfill because of more rapid waste degradation and increased gas production rates. Recovering landfill gases will help but may not eliminate odors. Other measures are also likely to be required, including geosynthetic caps, odor masking agents and biofilters to reduce odors. A biofilter is an organic media (like compost) used to de-odorize gases prior to discharge into the atmosphere. Biofilters can be effective at reducing odors.

More, smaller cells. Unlike a traditional landfill in which the goal is to use each cell for as long as possible, bioreactors rely on waste decomposing to extend the available life. However, if a large cell is converted to a bioreactor, settlement induced by liquids addition is difficult to utilize as available airspace. When settlement occurs in a large cell, some of the settlement (estimated at 10 to 30 percent) occurs on the side slopes. The settlement on the side slopes is difficult to reuse due to operational limitations. Normally, if the settlement on the side slopes is less than 5 feet vertical, placing waste in the settled area or a side slope is not cost effective due to the inefficiency of placing shallow lifts of waste and covering the waste on the slope. Bioreactor landfills with recovery use more, smaller cells to enhance rapid decomposition. Bioreactors landfills without recovery use larger cells in an attempt to gain airspace through rapid settlement.

2.1.3 Operation

Bioreactor landfills are filled much like conventional landfills. Municipal solid waste (MSW) is placed with a dozer or compactor and compacted in each cell. A balance is recommended between compaction and recirculation. Dense waste compaction slows waste saturation and contributes to developing preferential flow paths for liquids. Loose waste placement exhausts airspace sooner; thus, a balance must be maintained between recirculation and compaction. This balance is estimated to be in the 900 to 1,100 pounds per cubic yard effective waste density.

As each cell is filled, it is covered with a cover. The cover may be a geomembrane or soil depending on the type of bioreactor operation. The cover serves several purposes including:

Enhanced gas recovery
Reduced air infiltration
Control of odors caused by rapid decomposition of wastes
Controlling moisture levels
Providing freeze/thaw protection for leachate and gas systems

Operation of a bioreactor landfill can be classified as (1) with recovery or (2) without recovery. Bioreactor landfills with recovery will ultimately be excavated and the waste processed to obtain recyclables and humus. The inert fraction remaining will be placed in an inert landfill. Only a few bioreactors, mostly test cells, have been operated in this manner.

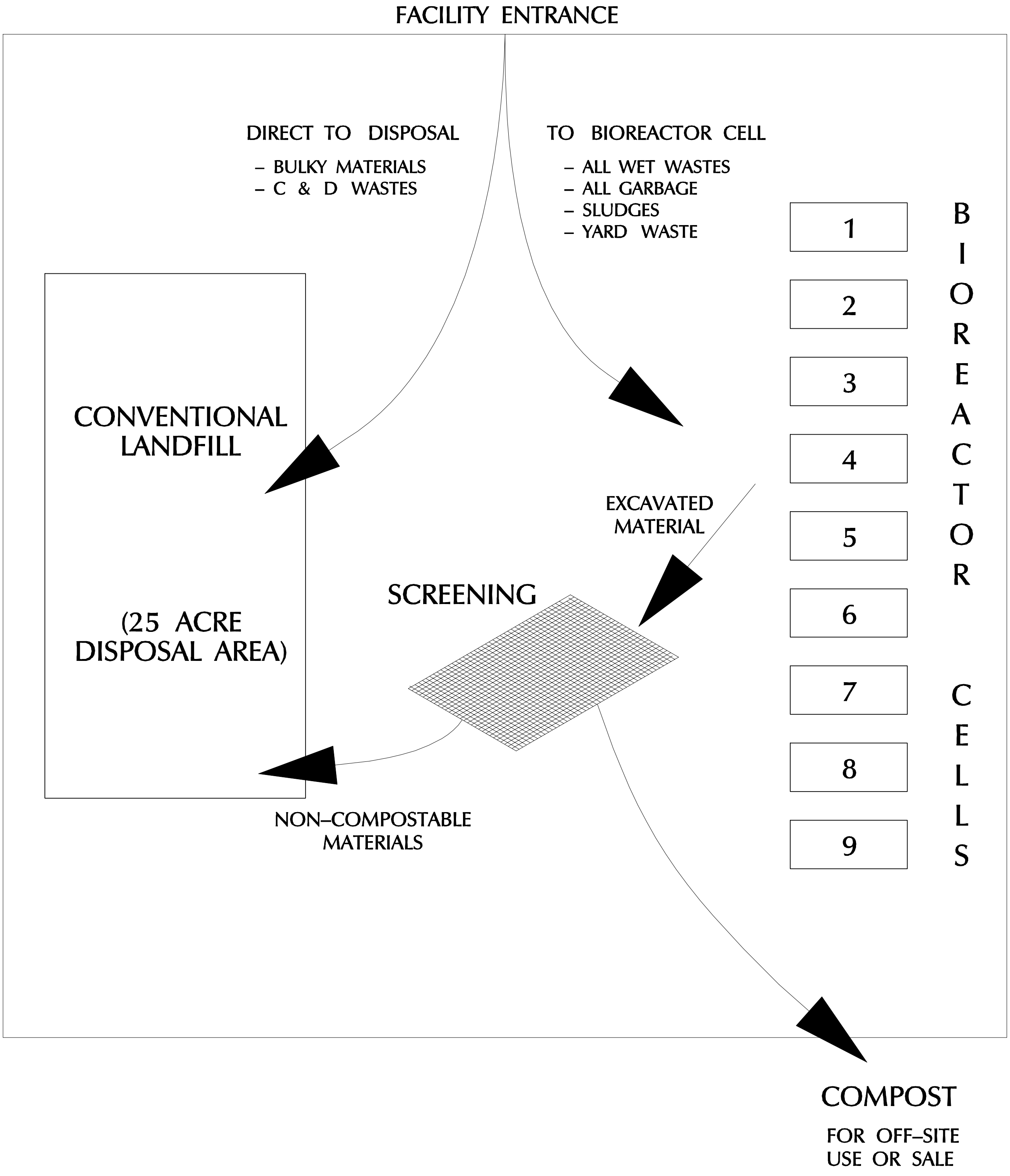
As each cell is filled and closed, waste disposal moves to the next available cell. Filled and capped cells are monitored for a period of years (typically seven to ten). Over time, many of the organic waste components (paper, food waste, yard wastes, etc.) decompose to a humus. When the organics are digested and the cell has stabilized, the cover is removed. The contents are mined and separated using a rotary or trommel screen. After the screening, the resulting humus could be marketed or used on-site as a soil conditioner. The separated, non-decomposed waste would be landfilled.

The liner, leachate collection system, leachate recirculation system, gas collection system, and cover of the emptied cell can be repaired and/or upgraded, if needed, before fresh waste is placed and the process repeated.

Figure 2-1 shows a conceptual site layout for a bioreactor landfill system based on a seven-year decomposition schedule. To accommodate a year of cell filling, seven years of decomposition, and a year of landfill mining, the owner would build nine bioreactor cells.

Figure 2-2 shows a cross section of a single bioreactor cell. The figure incorporates vertical gas collection wells. Horizontal gas collection wells are also common in bioreactors.

The vast majority of bioreactor landfills are operated without recovery. Their operation focuses on increased landfill gas production, avoidance of leachate disposal costs and capturing of additional airspace due to settlement from waste degradation. The goal is not to excavate the waste, but to recover airspace.



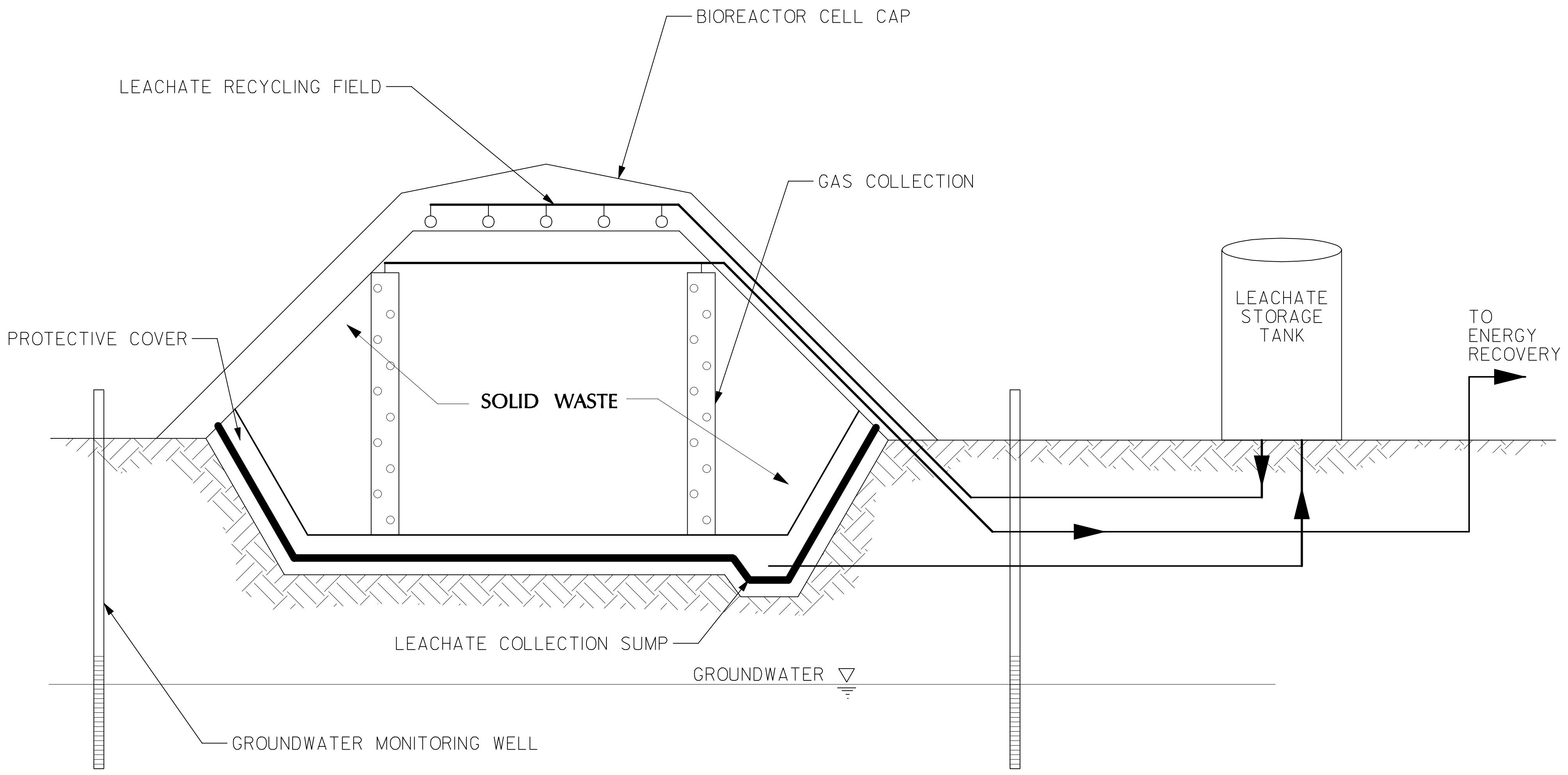
RAMSEY/WASHINGTON COUNTIES

FIGURE 2-1

CONCEPTUAL SITE LAYOUT
FOR 7-YEAR DECOMPOSITION SCHEDULE

Scale: NOT TO SCALE Date: APRIL 2000

Prepared By: **Foth & Van Dyke** By: JAM3



RAMSEY/WASHINGTON COUNTIES

FIGURE 2-2

BIOREACTOR CELL
CROSS SECTION

Scale:	NOT TO SCALE	Date:	APRIL 2000
Prepared By:	**Foth & Van Dyke**	By:	JAM3

Bioreactor landfills without recovery operate much like regular MSW landfills. However, with a bioreactor, liquids recirculation facilities are added and enhanced gas recovery systems are installed. These bioreactor landfills can be operated sequentially, in that an area of a cell is filled and leachate recirculation facilities are installed. The area is saturated while waste is placed in another area of a cell. When the second area reaches a predetermined height, leachate recirculation facilities are added and landfill operations are moved to the first area. This method of operation takes advantage of increased airspace through settlement. However, this mode of operation can make landfill gas recovery difficult. Operating in this fashion takes considerable planning and engineering to ensure proper recirculation strategies are developed and implemented, filling sequences are determined, cell access issues are addressed and landfill gas collection and control systems are installed and maintained while active filling is going on. Usually, the landfill operators play a large role in recirculation and landfill gas facility installation with this type of operation.

2.2 Markets for Recovered Materials

2.2.1 Recyclables

Recyclables would only be recovered in bioreactor landfills with recovery. It may be difficult for non-organic curbside recycling-type materials (glass, tin or aluminum cans) excavated from a bioreactor cell to meet market specifications. However, it may be possible to recover and market larger metal components, if those wastes are not excluded prior to waste placement.

2.2.2 Landfill Gas

Bioreactor landfills produce significant amounts of LFG. For example, the Bluestem Solid Waste Agency (recent name change to Cedar Rapids/Linn County Solid Waste Agency) pilot project located in Marion, Iowa, originally estimated that gas recovery potential could reach 2,800 to 11,250 standard cubic feet per day (scfd) in its 1-acre cell.[5] In 2003, the bioreactor was generating over 14,000 scfd. This can be attributed to increased moisture content in the cell.

The Yolo County, California, bioreactor pilot project notes that the bioreactor cell pilot project, which measures results from a cell containing 9,000 tons of MSW, has the potential to generate about 50 million cubic feet of landfill gas while decomposition continues. The study noted that the methane recovery rate from the bioreactor cell is “approaching ten times that normally expected from conventional landfills.”

LFG must be managed. Depending on the proximity of a bioreactor project to additional gas generation sources (e.g., landfills) and markets, the gas should be marketable. More details on options for LFG collection, control and conversion are discussed in Section 4.

Increased landfill gas production has several benefits. Landfill gas consists of methane and carbon dioxide, as well as trace amounts of other contaminants. Because methane is a potent greenhouse gas, collection for beneficial reuse helps the environment.

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[5] E&A, August 1997.

Landfill gas can be used on and off-site in a variety of ways. Using readily available technology, landfill gas uses may include:

Fuel source for electric power generation
Fuel source for on-site vehicles
Cleaned and sold as natural gas
Used as a heat source for on-site or nearby buildings

As a result, landfill gas has available markets and may be considered a benefit of the bioreactor process. Since using a bioreactor landfill speeds gas production, the site must be prepared to collect and process landfill gas sooner than in a conventional landfill.

2.2.3 Soil Product[6]

In the limited application of bioreactor landfills with recovery, after the cells have been mined and the materials screened, the resulting under-sized fragment is likely to consist of humus-like materials produced from degraded organic wastes. This raw soil product is likely to contain residual volatile acids that cause odor and limit or prohibit seed germination. In the Bluestem bioreactor pilot project, it was recommended that Bluestem use a short period of aerobic windrow composting to improve the marketability of this product. It is also noted that exposure to rainfall would reduce high soluble salt contents if present, thus further increasing marketability.

Because Bluestem currently operates an extensive biosolids composting facility, the recommendation about incorporating a final composting phase was also intended to capitalize on already existing facilities and operations. Bluestem intends to evaluate these recommendations when the bioreactor is mined in 2007.

2.3 Current Uses

2.3.1 Existing Uses of Relevant Technology Components

There are several components to bioreactor technology, each of which is in varying degrees of use. The following sections examine bioreactors and landfill mining (used with bioreactor landfills with recovery) and discuss current uses.

2.3.1.1 Bioreactors

Several bioreactor landfills are in various stages of development and operation in 19 states. Most bioreactors are anaerobic (without oxygen) but some new pilot studies are also being conducted on aerobic bioreactor cells and hybrid cells that use both aerobic and anaerobic methods in alternating fashion.

A 2003/2004 SWANA Bioreactor Landfill Committee completed a list of known bioreactor projects in North America. The list is summarized in Exhibit 2-1.

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[6] E&A, August 1997.

Exhibit 2-1

Bioreactors

Summary List of North American Bioreactor Landfill Projects

Landfill Name	Landfill State	Bioreactor Type	Start Date	End Date	Wetting Method	Scale (acres)	Leachate Circulation	Other Liquids	Sludge Added	Air Injection	Vacuum Air	Active LFG System
Onyx Cedar Hill Landfill	Alabama	Anaerobic	2000		spray	Full	Yes	Yes	yes	no	no	Yes
Onyx Star Ridge Landfill	Alabama	Anaerobic	2000		Injection and spray	Full	Yes	Yes	yes	no	no	Yes
Aquatera Landfill	Alberta Canada	Anaerobic	2001		injection/ vertical	Demonstration	Yes	Yes	yes	no	no	Yes
Onyx Pine Ridge Landfill	Bahamas	Anaerobic				Full	Yes	Yes				Yes
Mountain View LF	California	Anaerobic	1982	1982	Injection	Demonstration	Yes	Yes	yes	No	No	No
Yolo County Central LF	California	Anaerobic	1994			Demonstration	Yes	Yes	No	No	No	No
Naples SLF Cell #6 Collier County	Florida	Aerobic	1990	1992	Lysimeter	Lab	Yes	Yes	No	Yes	No	No
New River Regional LF	Florida	Aerobic & Anaerobic	2002		Injection	Full	Yes	Yes	No	Yes	No	No
Highlands Cty Solid Waste Mgnt Ctr	Florida	Anaerobic	2000		Horiz Leach. Inj	Full	yes	yes				yes
LaGrange Sanitary Landfill	Georgia	Anaerobic	2003	2025	Pumped	50	Yes	Yes	Yes	No	No	Yes
WMI-Live Oak Landfill	Georgia	Aerobic	1997	1999		Full	Yes	Yes	No	Yes	No	No
Central Disposal LF	Iowa	Anaerobic	2001		Injection	Full	Yes	Yes	No	No	No	yes
Bluestem Landfill Site #2	Iowa	Anaerobic	2001	2006	Injection	Demonstration	Yes	Yes	Yes	No	No	yes
Onyx Zion Landfill	Illinois	Anaerobic	2002			Full	Yes	Yes				Yes
Onyx Valley View Landfill	Illinois	Anaerobic	1998			Full	Yes	Yes				Yes
Onyx Blackfoot Landfill	Indiana	Anaerobic	1999			Full	Yes	Yes				Yes
Outer Loop RDF	Kentucky	facultative	2002		injection		yes	Yes	No	No	No	Yes
Outer Loop RDF	Kentucky	facultative	2002		injection		yes	Yes	no	no	no	Yes

Exhibit 2-1

Bioreactors

Summary List of North American Bioreactor Landfill Projects

Landfill Name	Landfill State	Bioreactor Type	Start Date	End Date	Wetting Method	Scale (acres)	Leachate Circulation	Other Liquids	Sludge Added	Air Injection	Vacuum Air	Active LFG System
Outer Loop RDF	Kentucky	facultative	2002		Injection		yes	Yes	Yes	Yes	No	Yes
Millerville SLF	Maryland	Anaerobic			Injection		Yes	Yes	No	No	No	No
Forest Lawn Landfill	Michigan	Anaerobic	1999	ongoing								
Cape May County LF	New Jersey	Anaerobic	2001	ongoing	Injection	Full	Yes	Yes				
Burlington Co. LF	New Jersey	Anaerobic	2002		injection		yes	yes	no	no	no	yes
Cumberland County Solid Waste Complex	New Jersey	Aerobic	2003	2007	Vert Inj Wells	11	Yes	Yes	No	Yes	No	Yes
Greater Albany SLF	New York	Aerobic	1989	1995	Spray	Full	Yes	Yes	No	Yes	No	No
Ontario County SLF	New York	Aerobic	1998	1998	Spray	Full	Yes	Yes	No	Yes	No	No
Onyx Greentree Landfill	Pennsylvania	Anaerobic	2000			Full	Yes	Yes				Yes
Berkely County Landfill	South Caroline	Anaerobic	permit rvw		Spr & Injection	Full	Yes	Yes	No	No	No	Yes
Hamilton County LF	Tennessee	Aerobic	1999	2000	Injection	Full	Yes	Yes	No	Yes	No	No
King George County LF	Virginia	Anaerobic			Injection		Yes	Yes	Yes	No	No	Yes
Deer Track Park Incorporated LF	Wisconsin	Leachate Recirculation			Spray		Yes	Yes	No	No	No	Yes
Lake Area Disposal LF	Wisconsin	Leachate Recirculation	2001				Yes	Yes	No	No	No	Yes
Mallard Ridge LF	Wisconsin	Leachate Recirculation	1996	1998	Injection	Full	Yes	Yes	No	No	No	Yes
Metro Recycling and Disposal LF	Wisconsin	Hybrid			Injection	Separate Cell	Yes	Yes	Yes	Yes	No	Yes
Superior Glacier Ridge LF	Wisconsin	Leachate Recirculation	1999		Spray	Full	Yes	Yes	No	No	No	Yes
Timberline Trail Landfill	Wisconsin	Leachate Recirculation	2001				Yes	Yes	No	No	No	Yes

K:\scopes\04R004\Reports\bioreactorlist.xls

Exhibit 2-1

Bioreactors

Summary List of North American Bioreactor Landfill Projects

Landfill Name	Landfill State	Bioreactor Type	Start Date	End Date	Wetting Method	Scale (acres)	Leachate Circulation	Other Liquids	Sludge Added	Air Injection	Vacuum Air	Active LFG System
Valley Trail LF	Wisconsin	Leachate Recirculation	1999	2001	Spray	Full	Yes	Yes	No	No	No	Yes
Onyx Hickory Meadows Landfill	Wisconsin	Anaerobic	2002			Full	Yes	Yes				Yes

K:\scopes\04R004\Reports\bioreactorlist.xls

The list indicates there are 26 active bioreactor landfill projects in North America. Of the active projects, four bioreactors are aerobic (inject air). Twenty-two are anaerobic bioreactors. The most common practice for re-injection of leachate is by either vertical or horizontal piping. However, some apply leachate via spray methods.

Because preliminary findings and opinions from some of the bioreactor landfills were already incorporated in the previous technology discussions, they are not presented in greater detail here.

2.3.1.2 Landfill Excavation (Mining)

Operating data is limited on the use of landfill excavation *in conjunction with* bioreactor landfill operation. The Bluestem Solid Waste Agency pilot project is one of only a few that has incorporated such a step in its planning. Excavation is unlikely to occur until at least 2007 in that project. However, there is an increasing body of knowledge about landfill excavation for other purposes. The following examples highlight only a few projects that used landfill excavation technologies.

The Collier County, Florida, Landfill began a landfill reclamation project in 1987. The original intention was to investigate the potential to reclaim buried cover soils for reuse and to recover combustibles as fuel for a planned waste-to-energy facility. The incinerator was not built, but using standard excavating equipment and a three-tiered vibrating screen, the County did successfully separate excavated waste into a soil-like fraction and an oversize fraction.[7]

In 1990 and 1991, 1 acre of the 5-acre Town of Edinburg (Saratoga Co., NY) was reclaimed in an effort to reduce the size of the landfill footprint. The project= s success depended on the ability to mine the landfill, recover the land for productive use, and get the reclaimed soil-product reclassified as something other than solid waste.

Approximately 15,000 cubic yards of landfilled material were excavated and screened. Of this, about 50 percent passed through a 2-inch screen and were, after testing, approved for use as clean fill. Another 25 percent of the excavated material was found to consist largely of Arecyclable≅ cans and bottles. The remaining 25 percent, consisting primarily of large (greater than 3 inches) fragments of plastics, textiles, paper, grubbing, wood and metal, was evaluated as a fuel source.[8] No further data was found about project results.

In 1998 and 1999, Waste Management, Inc.'s (WMI's) Deer Track Park Landfill at Watertown, Wisconsin completed a project to relocate approximately 646,000 cubic yards of waste from a closed, unlined landfill into an adjacent composite-lined facility. The project involved recovering tires, white goods, and batteries from the mined waste; and separating non-degraded wastes from daily cover soils and fully-degraded wastes through the use of a trommel screen. After the waste materials were excavated, non-contaminated soils beneath the closed landfill were used for

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[7] Morelli, John; "Landfill Reclamation: An Alternative to Closure and Siting," *MSW Management*. September/October 1991: 33-37.

[8] Morelli.

constructing berms in an expansion area, and the recovered airspace was reused by placing a composite liner at its base.

2.3.1.3 Bioreactors and Composting

Bioreactor landfills canco mpliment an integrated waste management system. Even systems with aggressive organics collection and composting can benefit from disposal of the remaining MSW in bioreactor landfills. According to industry estimates, landfills currently contain 5 billion tons of organic wastes, with over 125 million tons being added each year[9]. Bioreactor landfills are a method of treating the organic material that is ending up in landfills, even with aggressive organics collections programs. Furthermore, bioreactor landfills and organic processors are not necessarily targeting the same waste streams.

Todd Watermolen, Vice-President of Engineering for the Onyx Waste Services, states, "Composters pursuing the organic fraction of the waste stream are typically doing a good job of managing green and yard waste. If they can extract additional organics, all the power to them. We're just trying to treat and break down the waste that normally would come into the landfill facility through the solid waste stream[10]." James McNelly, President of Renewable Carbon Management LLC of St. Cloud, counters, "Last year, waste management firms attempted to repeal the yard waste ban in Iowa[11]." However, the repeal was proposed by the city of Des Moines to reduce collection costs. The measure was defeated. McNelly also cites a similar attempt in Indiana. Legislative measures to increase organics in landfills in Minnesota would likely be defeated. In addition, R/W counties have always supported the highest and best use of materials prior to landfilling. Clearly composting organic materials is a better use of organics, rather than bioreactor landfills. Nevertheless , bioreactor landfills provide a valuable process to the integrated system by converting organics remaining in the waste to useable methane and inert material.

2.4 Permitting/Regulatory Issues

Current Subtitle D landfill regulations are based on the premise of reducing leachate generation. This is accomplished by limiting the amount of liquid entering the landfill via operational controls and time limits on landfill capping. While waste stabilization is recognized as a benefit, it is considered secondary in the current regulatory structure.

To encourage bioreactor landfills, the primary function of landfills must be changed from entombment to containment, waste treatment and stabilization. This would require regulatory changes to permit bioreactor landfills thatadd and utilize various liquid sources.

The regulatory climate for bioreactors is increasingly favorable nationwide, though most regulatory agencies, including the Minnesota Pollution Control Agency (MPCA), do not currently permit bioreactor landfills. This mind set is changing in some locations as additional data is gathered from pilot studies.

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[9] Fickes, Michael. "Seeing Green," *Waste Age*. August 2004. pg. 35.
[10] Ibid, pg. 37.
[11] Ibid, pg. 37.

Additionally, on March 22, 2004, the USEPA issued the final rule on Research, Development and Demonstration (RD&D) permits for MSW landfills. This final rule allows directors of approved states, like Minnesota, to issue variances for bioreactor landfills (and also alternative final caps). The first step in the process is for the state to adopt regulations (subject to EPA approval) to implement the RD&D provisions of the federal statute. Minnesota received authority from the EPA for RD&D projects on September 10, 2004 (69 FR 54756). The RD&D permit can only be for 12 years, after which, a site-specific rule can be issued by EPA for the project or further federal rule revisions would be needed to authorize continuation of the project.

In the short to medium term, it is unlikely the MPCA will permit full-scale bioreactors in Minnesota[12]. MPCA currently has a pilot program for leachate recirculation landfill projects, which is discussed later.

2.5 Applicability to Ramsey/Washington Counties' Waste Stream

2.5.1 Targeted Waste Streams

The current waste stream for Ramsey/Washington counties (prior to processing) consists of degradable materials of about 26 percent organic materials, and 35 percent paper. Thus, about 61 percent of the waste stream could be decomposed in a bioreactor landfill, assuming no additional recycling or recovery. This percentage is not unusual from a landfilling perspective. This waste stream could be suitable for bioreactor landfill technology.

In addition, the current RDF waste stream would provide an excellent media for bioreactor landfill technology. The upfront processing to remove bulky and inert materials and shredding of the waste, would enhance the benefits of bioreactor landfill technology and increase recovery of the humus material created.

However, for either waste streams, a pilot cell project could be implemented before full-scale operation. A smaller cell, much like the 1-acre Bluestem bioreactor, could be constructed to store and bioreact a fixed waste quantity. The cell would be instrumented with temperature and moisture probes and be designed to collect and recirculate leachate and collect landfill gases. Ideally, two side-by-side cells would be constructed to examine the rate of stabilization of the two waste streams. The pilot study would provide the needed data to develop a bioreactor landfill with recovery project for a larger waste stream and examine the cost/benefit of the RDF pre-processing of the waste.

2.5.2 Capacity/Flexibility

Much like a traditional landfill, a bioreactor landfill will accept almost any MSW that individuals deliver to it. However, long-term degradation and recovery are likely to be driven by the extent to which non-organic wastes are segregated prior to landfilling. This report notes that paper and organic materials made up approximately 61 percent of the Ramsey/Washington counties' waste stream. This is the fraction most likely to be converted to landfill gas and a reusable soil-like product.

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[12] Conversation with Gorden Wegwart, MPCA, May 25, 2004.

Bioreactor landfills are somewhat flexible in much the same way that a traditional landfill offers flexibility:

> Cells are built in phases rather than all at once, allowing an entity to construct an alternative processing facility rather than another cell.
>
> A bioreactor landfill equipped for liquids addition and gas recovery has been demonstrated to be more effective than a standard dry tomb landfill in degrading waste.

2.5.3 Site Needs

Site needs for a bioreactor landfill are similar to that of a traditional landfill in that a site must be able to receive incoming waste, have available cells to accept the waste, and house support facilities. In order to provide some basis for comparison of technological concepts, Foth & Van Dyke made some preliminary estimates for a bioreactor landfill with the following MSW annual tonnages[13]:

2007	615,000
2010	675,000
2017	800,000

This approximates the MSW quantities potentially available for processing. A bioreactor landfill operating for 30 years would need about 500 acres. Additionally, another 100 acres would be needed for buffers, roads and facilities. Thus, the total acres needed for a bioreactor landfill would be 600 acres.

If we assume direct landfilling of all waste, without bioreactor landfill technology, the estimated required cell area would be 700 to 900 acres.

If a bioreactor landfill served as a complement to continued RDF combustion in the future, the total volumes going to the bioreactor landfill would be reduced and the site size required would decrease accordingly.

2.5.4 Economics and Risks

2.5.4.1 Economics

The bioreactor landfill offers several potential benefits, including rapid waste stabilization, better gas production, and better leachate management and all the benefits associated with it. However, the benefits can not be achieved without additional costs for recirculation piping, gas collection systems and additional permitting requirements.

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[13] Taken from Table 2-3, *Updated Research Study of Alternative Waste Processing Technologies*, Foth & Van Dyke.

In 2001, Gary Hater published an article based on WMI's experience operating a dozen bioreactor landfills[14]. The article examined potential economics for eight types of bioreactor landfills compared to a traditional Subtitle D landfill. The article reported the following economics (Table 2-1), which may or may not be applicable to the Ramsey/Washington counties waste stream.

Table 2-1 Estimated Bioreactor Costs

Landfill Type	Aerobic Bioreactor	Anaerobic Bioreactor	Hybrid Bioreactor	Traditional Subtitle D Landfill
Assumed Density (lbs/cy)	1,950	1,950	1,950	1,500
Site Life (years)	27	27	27	21
Site Life increased capital investment ($, millions)	$4.0	$6.0	$9.5	N/A
Annual Increase – Liquids Revenue ($, millions)	$1.8	$1.8	$1.8	N/A
Annual Increase in Operating Cost ($, millions)	$0.5	$0.3	$0.4	N/A
Annual Increase – Gas Production Revenues ($, millions)	($0.9)	$1.5	$1.5	N/A

Table 2-1 shows the added site life, increased capital costs, increased annual revenues and costs. The analysis did not include several variables, including reduced post-closure costs, airspace increase that contributes to potential revenue and cost avoidance for leachate transport and treatment off site.

Shaw and Knight[15] published an article examining costs based on increased airspace, increased construction and leachate disposal avoidance. They report increased density of the waste as a result of liquids recirculation can save $7 to $12 million for a 50-acre landfill. Reported costs for liquids recirculation facilities ranged from $160,000 for horizontal trenches to $640,000 for vertical trenches based on an 8-acre cell. Leachate treatment avoided costs were reported on a 10-acre cell to be $54,750 to $602,250 per year. Finally, increased revenues from airspace gains were estimated to be $6,667 per day based on a 500 tons per day operation at a tip fee of $40 per ton and an average density increase due to bioreactor operations of 600 pounds per cubic yard.

The analysis provided by Shaw and Knight provides some potential economics of bioreactor landfills but it is difficult to apply the economics directly to Ramsey/Washington counties.

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[14] Hater, Gary et al., "Economics of Eight Scenarios for Landfill Bioreactors as Compared to a Base Subtitle D Landfill," WasteTech 2001.

[15] Shaw, Prentiss and Amy Knight, "Landfill: Bioreactor Landfills: But Does it Save Money?" *Waste Age*, July 2000.

Kuniholm[16] concluded in his study bioreactor landfills have an increased net annual cost to operate of $0.50 to $1.00 per ton; however, long-term savings from addition airspace and avoided construction costs due to increased cell life were not considered.

From the studies completed on the economics of bioreactor landfills, the following conclusions can be made:

- Bioreactor landfill feasibility is driven by local economics; the key factors being avoided leachate disposal costs, increase in waste density, potential to accept other liquids and charge for them.

- There are unknowns regarding key economic drivers such as ability to recapture airspace and reducing post-closure costs.

For Ramsey/Washington counties, the local economic factors would depend on location of the bioreactor. From discussions with WMI and BFI staff, it is believed Ramsey/Washington counties' waste could be managed in a bioreactor landfill at the current landfill disposal tip fee ($20 to $30 per ton) or even slightly less[17]. A cell dedicated to just Ramsey/Washington counties' waste would have less economy of scale than a larger operation.

2.5.4.2 Risks

With all new technologies, there are potential drawbacks. Bioreactor landfill technology, being relatively new to the MSW management arena, has potential downsides. As with costs, risks carry a local aspect to associated costs for risks or risk avoidance. The following discusses the general risks with potential bioreactor landfill operation.

2.5.4.2.1 Increased Gas Emissions

A bioreactor landfill will generate more LFG in a shorter time. The risk for odor generation is increased with a bioreactor landfill. Also, larger LFG collection systems are required to be installed sooner in a bioreactor landfill. With aerobic bioreactors, there is also the risk of subsurface landfill fires due to the introduction of oxygen into the waste mass.

2.5.4.2.2 Increased Investment and Operating Costs

With bioreactor landfills, added investment is required to construct the liquids recirculation system. This investment may be at risk because the ability to obtain additional revenue to offset costs is not well understood and subject to local conditions and permitting. The liquids recirculation system will also require increased cost for operations and maintenance.

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[16] Kuniholm, Peter, "Landfill Gas Implications for Bioreactor Landfills," presented at the Federation of New York Solid Waste Association, May 8, 2001.

[17] Interviews with Waste Management and BFI staffs on June 29-30, 2004.

2.5.4.2.3 Leachate Seeps

With bioreactor landfills introducing liquids back into the waste mass, leachate seeps are a common occurrence. Most seeps are minor and can be remediated quickly. However, on occasion, leachate seeps can be substantial and expose the facility to an off-site leachate migration. The risk of leachate seeps can be minimized by proper operation and monitoring. For reference, WMI budgeted between $66,000 and $116,000 annually for leachate seep repairs at a large bioreactor accepting 2,700 to 3,700 tons per day[18]

2.5.4.2.4 Slope Stability

Slope stability in a bioreactor landfill is difficult to quantify since study of waste properties under various saturation profiles is limited and waste properties vary depending on composition. Over saturation of the waste is the primary cause of slope instability in a bioreactor. The risk of slope failure in a bioreactor landfill can be minimized by proper operations that monitor liquids introduction to reduce the potential for slope failure.

2.5.5 Implementation Needs and Timelines

Assuming the project was developed at an existing sanitary landfill site, the schedule for initial implementation of a bioreactor landfill, including liquids recirculation and gas recovery, is consistent with that of constructing a new dry tomb landfill cell. The current RD&D rule only allows bioreactor landfills in approved states that adopt appropriate regulations. For most states, this may require a two-to five-year process to promulgate. Thus, implementation of bioreactor landfill technology may be two to five years or longer away.

For bioreactor landfills to be fully implemented in Minnesota, laws and rules regarding bioreactor landfills have to be changed to allow demonstration projects and/or full-scale implementation. This has the potential to be achieved through EPA's new RD&D rules, but discussion with MPCA staff indicate full-scale bioreactors will not be considered for several years. The MPCA is in a "wait and see" mode. Waiting for leachate recirculation pilot projects to yield results in order to develop policies may take five to ten years[19]. This time period might be reduced due to interest expressed by private companies and/or public agencies.

In discussions with WMI staff,[20] they believe bioreactor landfills in adjacent states, like Iowa, may only be 18 to 24 months away from being fully approved. They further indicated, in their opinion, Minnesota will permit full-scale leachate recirculation in the near future (three to five years).

Developing a bioreactor landfill-with-recovery facility at a new greenfields site would require all of the steps involved in siting a new sanitary landfill. This has proven to be an extremely difficult process in the Twin Cities area in previous years and may not be feasible.

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[18] Hater, Gary et al., 2001.

[19] Conversation with Gordon Wegwart, MPCA, May 25, 2004.

[20] Interview with Waste Management, Inc., June 29, 2004.

2.5.6 Advantages and Disadvantages

Table 2-2 summarizes several potential advantages and disadvantages of bioreactor landfills.

Table 2-2 Potential Advantages and Disadvantages of Bioreactor Landfills

Advantages	Disadvantages
More rapid waste stabilization	Not fully proven technology as yet
Minimize long-term environmental liability	Potential for increased odors
Potential reduced post-closure time period	Increased potential for slope stability problems
Potential to obtain additional airspace due to settlement, which may minimize need for siting new landfills	Higher capital and operating costs than sanitary landfills
Enhanced gas production with potential energy recovery revenues	Bioreactors are not being considered as a full-scale technology by the MPCA
Improved leachate storage and treatment at lower costs	
Reduced leachate toxicity	
Does not compete with recycling and composting programs	

2.5.6.1 Advantages

Primary advantages appear to be the more rapid waste stabilization and reduced leachate toxicity, resulting in long-term reductions in groundwater contamination risks. This reduces the long-term potential liability associated with the current dry tomb landfill technology. In addition, leachate treatment costs may be handled via the recirculation aspect of the bioreactor. This can reduce operating costs, depending on the location of the bioreactor and available leachate disposal methods.

Leachate strength in bioreactor landfills tends to be reduced with each recirculation cycle. The waste tends to clean the leachate. This seems counterintuitive, but the microbes in the waste consume or bind the toxic substances when leachate passes through the waste. The reduction in leachate toxicity by using bioreactor landfill technology has been demonstrated at several pilot-scale and large-scale bioreactor landfills. Baker[21] reported leachate toxicity trends at WMI

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[21] Baker, John, "Leachate Trends in Bioreactors and Closed Landfills," presented at the USEPA Bioreactor Workshop, Crystal City, Virginia, February 27-28, 2003.

bioreactor landfillsto be declining after initial operation of the bioreactor. WMI further reports toxicity of the leachate is minimal after 0.4 pore volumes of liquid are injected into the waste.

The ability to increase airspace in bioreactor landfills may also reduce the total land area required to host new or expanded landfills, which seems very consistent with Minnesota=s proposed long term solid waste policy.[22]

A WMI study[23] of the life cycle of a traditional landfill and a bioreactor landfill accepting 1,000 tons per day confirmed the expectation that bioreactor landfills have significant environmental advantages over traditional landfills. The WMI report concluded reductions in greenhouse gases and total particulates is substantial and the increased methane recovery and energy conversion at a bioreactor landfill provides significant benefits. The WMI study was further supported by a study conducted by Menard et al.[24]. Menard concluded that traditional landfills require 26 percent more raw materials, generate 82 percent more waste products and have 91 percent more potential environmental impacts than bioreactor landfills.

2.5.6.2 Disadvantages

Bioreactors at a large scale size (greater than 1,000 tpd) are in the research stage. Overall, bioreactor landfills are an unproven technology at large- or full-scale size. There are potential odors associated with the bioreactor process. Finally implementing bioreactor landfill technology in Minnesota is not yet approved by the MPCA.

2.5.6.3 Observations

Despite the potential disadvantages, bioreactor landfill technology appears to offer some significant long-term advantages. The rapid waste stabilization, reduced long-term liability, and increased airspace aspects provide a significant advantage over dry-tomb landfills.

2.5.6.4 Bioreactor Landfills with Recovery

Bioreactor landfills with recovery have an added advantage of gaining more airspace by excavating each bioreactor cell and recovering the degraded organics (humus), recyclable materials and inerts.

Bioreactor landfills with recovery require the additional cost of mining the bioreactor cells and sorting the materials for re-use. Little cost data is available on the bioreactor cell reclamation process. In 1999, the Deer Track Park Landfill mining project indicated a cost of $5 per cubic yard to excavate waste and $3 per cubic yard to process the waste through a trommel screen. Trommeling of the waste at this project was discontinued because the waste was wet and

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[22] Minnesota Office of Environmental Assistance, *Solid Waste Policy Report* "Waste Management in Minnesota: A transition to the 21st century," January 2000.

[23] Jones, James R. et al., "A Life-Cycle Inventory Comparison of a Bioreactor and Traditional Subtitle D Landfill," WasteTech 2000, Orlando, Florida, March 6-8, 2000.

[24] Menard, Jean-Francois et al., "Life Cycle Assessment of A Bioreactor and an Engineer and Landfill for Municipal Solid Waste Treatment," September 2003.

difficult to separate. It is questionable whether large-scale bioreactor landfills with recovery would be viable or cost effective.

Bioreactor landfills with recovery would face the same regulatory issues as bioreactors landfills (not allowed in Minnesota at this time) with the additional burden of obtaining regulatory approval to mine the bioreacted waste. The MPCA does have considerable experience mining landfills in their Closed Landfill Program, which could improve regulatory approval to mine waste.

3. Leachate Recirculation

3.1 Technology Description

3.1.1 Overview

Leachate recirculation is a term used at MSW landfills that return leachate (and gas condensate) back to the waste. Leachate recirculation differs from bioreactor technology in that the goal of leachate recirculation is not necessarily to maximize decomposition or reach a specific waste moisture content. Rather, leachate recirculation is used to increase biological activity and avoid leachate disposal costs.

Typically, leachate recirculation landfills are anaerobic in nature. Aerobic and hybrid leachate recirculation landfills offer too many challenges for a limited increase in waste moisture content. Thus, aerobic leachate recirculation sites are not common.

3.1.2 Detail

Construction of a leachate recirculation landfill is like a bioreactor landfill. A system is designed to send the leachate collected back into the waste mass. This can be accomplished by spraying the leachate on the working face and/or re-injecting the leachate back into the waste mass by means of pumps and horizontal or vertical injection pipes.

As with bioreactors, leachate recirculation landfills may also need:

- Thicker than standard protective layer and drainage layer
- Enhanced gas recovery systems
- Odor control measures

Unlike bioreactors, moisture addition is limited to the amount of leachate recovered at a landfill. Thus, optimum waste saturation is typically not achieved in leachate recirculation landfills except in wet climates like the East, Southeast and portions of the Pacific Northwest.

3.1.3 Operation

Leachate recirculation landfills are operated similar to bioreactors without recovery. Typically, an area of a landfill, or cell, is filled to a prescribed height with MSW. While MSW is being disposed in another area, the filled area is fitted with a leachate recirculation system and leachate is recirculated into the filled area. Leachate collected from all areas is typically recirculated. That is, leachate recirculation is not limited to recirculating leachate from only the cell it was collected from. This allows for more rapid stabilization of an area and increased settlement. However, this mode of operation makes landfill gas recovery difficult. Significant engineering and planning is required to obtain optimum performance (e.g., maximizing leachate recirculation, gas recovery and settlement).

3.2 Markets for Recovered Materials

The only material to be recovered from a leachate recirculation project is landfill gas. However, recovery of landfill gas prior to closure of an area is complex. Thus, landfill gas recovery at leachate recirculation landfills is difficult since leachate recirculation increases settlement of the waste; this increases useable airspace and thus delays closure. Leachate recirculation will increase gas production rates over that of "dry tomb" landfills. However, in most areas of the country, gas production rates from leachate recirculation landfills will not reach the levels of bioreactor landfills.

Landfill gas does have value and can be used in a variety of applications. Depending on the amount of gas produced, landfill gas can be:

- Used as a fuel source for electric power generation
- Used as a fuel source for on-site vehicles
- Used as a fuel source for heating
- Cleaned and sold as natural gas

The current climate for landfill gas development projects is limited. The lack of the tax credits or other financial incentives makes landfill gas projects unattractive to investors except at large facilities that can produce landfill gas in quantities sufficient for economies of scale to be profitable. Small to medium sized landfills typically flare the landfill gas as a control measure rather than investing in beneficial re-use of the landfill gas.

3.3 Current Uses

Traditional landfills are utilizing leachate recirculation in several states to take advantage of the benefits of leachate recirculation. A 2003/2004 SWANA study indicated 36 leachate recirculation projects currently underway in North America.

The SWANA list of active leachate recirculation projects is presented in Exhibit 3-1.

In Minnesota, the MPCA reports that it has received nine applications for leachate recirculation demonstration projects. These projects were selected based on the MPCA's alternative leachate management policy. In 2004, only Spruce Ridge, Elk River and Crow Wing are actively recirculating leachate. Lyon County and the Burnsville Sanitary Landfill are in the final stages of approval to begin leachate recirculation. One project, Nobles County, dropped out of the program. East Central Solid Waste Commission was added to the program in 2003 and is currently in the permitting process. Superior (now Onyx) Forest City Road Landfill began a leachate recirculation project but discontinued the project due to odor issues, leachate seeps and neighbor complaints. The remaining project, Polk County, was proposed but not constructed and is inactive.

Exhibit 3-1

Leachate Recirculation

Summary List of North American Bioreactor Landfill Projects

Landfill Name	State	Type	Start Date	End Date	Wetting Method	Scale (acres)	Leachate Circulation	Other Liquids	Sludge Added	Air Injection	Vacuum Air	Active LFG System
Fort Smtih Landfill	Arkansas	Anerobic	2004		Injection	Full		No		No	No	yes
Yolo County Landfill	California	Aerobic & Anaerobic	2000			Full	Yes	No	No	No	Yes	Yes
DSWA Central SWM Center	Deleware	Anaerobic	1985	ongoing	Gravity & Injection	Full	Yes	No	No	No	No	No
Baseline Landfill	Florida	Anaerobic	1992		Horiz & Vert Inj	Full	Yes	No	No	No	No	Yes
North Central Landfill	Florida	Anaerobic	2001		Horiz Leach. Inj	Full	No	No	No	No	No	No
Winfield Landfill	Florida	Anaerobic	1992			Full	Yes	No	No	No	No	No
Superior Pecan Row MSW Landfill	Georgia	Leachate Recirculation			Injection	Full	Yes	No	No	No	No	No
Onyx Orchard Hills Landfill	Illinois	Anaerobic	2003			Full	Yes	No				Yes
Outer Loop RDF	Kentucky	Hybrid	2002				Yes	No	No	No	No	No
Worcester County Landfill	Maryland	Anaerobic	1990		Vert. Wells	Full	Yes	No	No	No	No	No
Northern Oak Landfill	Michigan	Anaerobic	2002		Injection		Yes	No	Yes	No	No	Yes
Spruce Ridge LF	Minnesota	Anaerobic	1997	2003	Horiz. Dist		Yes	No	No	No	No	Yes
Crow Wing County Landfill	Minnesota	Leachate Recirculation	1998	ongoing			Yes	No	No	No	No	No
Lemons SLF, Inc	Missouri	Anaerobic	1994		Vert Wells / Horiz Distrb	Full	Yes	No	No	No	No	Yes
Showme Regional LF LLC	Missouri	Anaerobic	1997		Horiz dist	Full	Yes	No	No	No	No	yes
Black Oak LF	Missouri	Anaerobic	1995		Horiz. Dist	Full	Yes	No	No	No	No	No
Onyx Oak Ridge Landfill	Missouri	Leachate Recirculation	1989		horizontal	Full	Yes	No	No	no	no	Yes
Onyx Maple Hill Landfill	Missouri	Leachate Recirculation	2003		horizontal	Full	Yes	No	No	no	no	No
Plantation Oaks LF	Mississippi	Hybrid					Yes	No	No	No	No	No
Buncombe County LF	North Carolina	Anaerobic	2003	2023	Gravity & Injection	Full	Yes	No	Yes	No	No	Yes
Coastal Regional SWM Authority Landfill	North Carolina				Injection	Full	Yes	No	No	No	No	No

Exhibit 3-1

Leachate Recirculation

Summary List of North American Bioreactor Landfill Projects

Landfill Name	State	Type	Start Date	End Date	Wetting Method	Scale (acres)	Leachate Circulation	Other Liquids	Sludge Added	Air Injection	Vacuum Air	Active LFG System
Pennsauken Sanitary LF	New Jersey	Anaerobic	2004/2005		injection	Full	yes	no	no	no	no	yes
Ocean County Landfill	New Jersey	Anaerobic	2000	ongoing	Cap system-injection	13	Yes	No	No	no	no	Yes
Salem County Landfill	New Jersey	Anaerobic	1999	2003	Trench	Full	Yes	No	No	No	No	yes
Colonie LF	New York	Anaerobic	1998		Injection	Recirculation	yes	No	Yes	No	No	Yes
Lycoming County LF	Pennsylvania	Anaerobic				Full	Yes	No	No	No	No	No
Lanchester Landfill	Pennsylvania	Anaerobic	2002	ongoing	Injection		Yes	No	No	No	Yes	Yes
GROWS Landfill	Pennsylvania	Anaerobic	2000	ongoing			Yes	No	No	No	No	yes
Ste Sophie Landfill	Ste Sophie, Quebec	Anaerobic	2002	ongoing	Injection	pilot/27	Yes	No	No	No	No	Yes
Cedar Ridge LF	Tennessee				Spray	Full	Yes	No	No	No	No	No
Williamson County LF	Tennessee	Aerobic	2000		Injection	Separate Cell	Yes	No	No	Yes	No	No
Atlantic Waste LF	Virginia	Anaerobic	1998		Injection		Yes	No	No	No	No	Yes
Maplewood RWD Facility	Virginia	Leachate Recirculation					No	No	No	No	No	Yes
Middle Penninsula	Virginia	facultative	2000		spray		Yes	No	No	No	No	Yes
Superior 7-Mile Creek	Wisonsin	Anaerobic	1996		Injection	Full	Yes	No	No	No	No	Yes
Superior Emerald Park LF	Wisonsin	Anaerobic	1998		Injection	Full	Yes	No	No	No	No	Yes

3.4 Permitting and Regulatory Issues

The regulatory climate for leachate recirculation is variable. Each state has their own position regarding implementation of this technology. For example, Iowa allows full-scale leachate recirculation with little to no additional monitoring requirements. However, Minnesota only allows selected "demonstration projects," with considerable recordkeeping and reporting. In discussions with MPCA staff, the current leachate recirculation demonstration projects will need to yield sufficient data to demonstrate efficiency of full-scale leachate recirculation[25].

For a leachate recirculation demonstration project in Minnesota, the applicant must request a permit modification. The MPCA will only review a leachate recirculation proposal outside of normal working hours. Thus, the applicant must agree to pay the overtime costs for MPCA staff to review the permit amendment application and write the permit modification documents. The permit amendment application must address the following components:

- Leachate generation
- Data needs and management
- Leachate recirculation system design
- Leachate volume recirculated
- Liner design
- Leachate collection system design
- Gas collection system design
- Slope stability
- Operating plans
- Waste characteristics
- Cover materials
- Final cover
- Inspection, monitoring and reporting requirements
- Contingency action plan
- Financial assurance
- Certificate of need requirements

During design and permitting, a variety of issues must be addressed including:

Gauging effects of leachate recirculation andcondensate on the leachate collection system
Managing odors and increased gas production
Avoiding saturation of the waste mass which can cause slope failure
Managing increased and differential settlement of the waste mass
Managing increased heat generation inside the waste mass

Monitoring requirements include:

- Quarterly leachate sampling
- Mercury analysis

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[25] Conversation with Gordon Wegwart, MPCA, May 25, 2004.

- Weekly leachate head monitoring
- Annual settlement monitoring
- Waste field capacity measurements annually
- Quarterly gas sampling and analysis

In addition, each facility with leachate recirculation must have at least two certified operators and maintain a log book of activities and data in support of leachate recirculation.

Leachate recirculation in Minnesota is in the "wait and see" mode. In the meantime, the MPCA will continue to gather and analyze data on the approved pilot projects and establish parameters to possibly expand leachate recirculation to other sites. Most of the current active leachate recirculation pilot projects are in a five-year study, with possible extensions. Thus, implementation of full-scale leachate recirculation at Minnesota landfills could be several years away before MPCA approval is granted[26]

3.5 Applicability to Ramsey/Washington Counties' Waste Stream

Leachate recirculation applicability to the Ramsey/Washington counties' waste stream is similar to that of bioreactor technology discussed in Section 2.5 and will not be discussed in detail here. However, in order for leachate recirculation to be implemented for Ramsey/Washington counties' waste stream, first a landfill must be sited, constructed and operational for some period of time before leachate recirculation can be conducted. However, siting a new landfill in Minnesota would be monumental and may not be economically viable.

A possible option could be to transfer Ramsey/Washington counties' waste to an existing landfill out of state. This would allow use of leachate recirculation technology without the costs and commitments of siting a new landfill.

WMI[27] indicated leachate recirculation is currently underway at their Lake Mills, Iowa, landfill and as a pilot project at the Spruce Ridge landfill near Glencoe, Minnesota. The Burnsville landfill is scheduled to start leachate recirculation in the near future. WMI believes Minnesota will allow full scale leachate recirculation in the next three to five years. Iowa is believed to be ahead on this issue, with permitting of full-scale bioreactor landfills in Iowa within two years. WMI indicated the tipping fee for a bioreactor landfill or leachate recirculation would be comparable to current landfill tipping fees, unless a specific dedicated cell would be required. Dedicated cells for Ramsey/Washington counties' waste would increase costs due to additional operation and monitoring costs. WMI was interested in the idea of Ramsey/Washington counties' waste being placed in a bioreactor landfill or leachate recirculation landfill.

BFI[28] has a large-scale leachate recirculation system at the landfill in Rice Lake, Wisconsin. For Ramsey/Washington counties, use of the Pine Bend Landfill is limited. BFI indicated they have 100 acres to the west of the existing site that has the potential to be developed into landfill space.

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[26] Conversation with Gordon Wegwart, MPCA, May 25, 2004.

[27] Conversation with Waste Management, Inc. staff, June 29, 2004.

[28] Conversation with BFI staff on June 30, 2004.

The facility in Rice Lake has significant expansion potential and could provide long-term disposal capacity to Ramsey/Washington counties. BFI was unsure of potential costs but would respond to any Request for Proposals issued by Ramsey/Washington counties for waste disposal.

4. Landfills with Methane Recovery

4.1 Technology Description

4.1.1 Overview

Solid waste placed in landfills decomposes over time by a combination of chemical, physical and biological processes. The physical and chemical processes are important to overall landfill performance; however, the biological process is the only process in a landfill that produces methane gas. Only the organic portion of the solid waste is converted to landfill gas (LFG). LFG contains approximately 50 percent methane and 50 percent carbon dioxide. LFG can also contain trace constituents that are normally less than 1 percent. LFG is typically captured by a LFG collection system or vented to the atmosphere. Currently, only landfills with 2.5 million megagrams (2.76 million tons) or 2.5 million cubic meters (3.25 million cubic yards) in place are required to have active gas collection systems (40 CFR 60). Gas systems can either be horizontal or vertical, with vertical systems being the most common. Once the LFG is collected, the gas can be either flared, converted to electricity via internal combustion engines, or microturbines, converted to pipeline quality natural gas, used as a fuel for a heat source (e.g., boiler) or used as other fuel.

4.1.2 Detail

Solid waste deposited in a landfill decomposes biologically in five principle phases. These phases generate LFG and are explained below[29].

> Phase 1 – Initial Adjustment. This phase is aerobic in nature and occurs as waste is placed in a landfill and soon thereafter. The organic portion of the waste undergoes microbiologic decomposition using microbes in the waste, cover soil and leachate.
>
> Phase 2 – Transition Phase. This phase is marked by the depletion of air and the transition from aerobic to anaerobic conditions. As the process becomes anaerobic, nitrate and sulfate are converted to nitrogen gas and hydrogen sulfide. Also, complex organics begin to break down to organic acids.
>
> Phase 3 – Acid Phase. This phase is indicated by an increase in the organic acid production and a decrease in hydrogen production. This phase mainly produces carbon dioxide and the leachate produced has a pH of 5 or lower.
>
> Phase 4 – Methane Fermentation Phase. In this phase, microorganisms convert the acids and hydrogen from Phase 3 into methane and carbon dioxide. Though acid formation continues in this phase, it is considerably reduced compared to Phase 3. Leachate in this phase will tend to be more neutral (pH around 7).

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[29] Tchobanoglous, George, et al. "Integrated Solid Waste Management Engineering Principles and Management Issues," McGraw-Hill, Inc., pp 382-390.

> Phase 5 – Maturation Phase. This phase occurs as the convertible organic material is exhausted. This phase still produces small quantities of methane and carbon dioxide but at reduced rates.

Each phase's duration is dependent on the amount of organic material, nutrients and moisture available in the landfill. Typically Phase 1 lasts only a few weeks to a few months. Phase II can occur rapidly as the oxygen is consumed in the landfill. Phase 3 and Phase 4 continue in various stages for several years. Finally, Phase 5 has a duration of decades where small amounts of methane and carbon dioxide are produced. Leachate recirculation and bioreactors tend to decrease the time required to convert organic materials to LFG. This limits the durations of Phase 4 and Phase 5 by rapidly converting organics more completely than dry tomb landfills.

LFG collection methods are different depending on the reason for collection and the end use of the LFG. For example, a LFG system for migration control may have perimeter control but not controls in the center of a landfill. LFG collection systems typically have the following components:

- Wells (either vertical or horizontal) placed in the refuse.
- A header system to connect the wells to a suction source.
- A flare/blower system. The blower provides suction; the flare is used if excess gas requires disposal or if the primary system breaks down.
- An end-use gas system, which can be motors, generators, turbines, boilers, gas cleaners, etc.

The LFG wells can either be constructed vertically through the waste or horizontally in the waste. The most common LFG collection well is constructed vertically through the waste. This is typically completed as an area of the landfill reaches the final grade. Vertical wells (from 24 to 36 inches in diameter), are drilled into the waste. A small diameter (usually 6 to 8 inches) slotted well casing is placed in the borehole. The annular space is filled with porous stone. The well casing is then connected to the solid header pipe. The connection is called a wellhead and consists of valves and measuring devices to control gas flow and suction in the well. Vertical well spacing is typically at a 150-foot to 300-foot radius.

Horizontal gas collection wells are placed about 50 to 100 vertical feet apart inside the refuse. They are usually installed during waste placement and can be operated prior to closure. The horizontal wells terminate at the side of a landfill where they are connected by a wellhead to a header that sends the gas to the control device. Horizontal wells have the benefit of collecting gas from a landfill sooner than vertical wells; however, horizontal wells can be severely impacted by waste settlement that can crush and break gas well pipes in the refuse.

4.1.3 Operation

Operation of a LFG collection system varies depending on the system and control device. Ideally, the system vacuum at the wellhead should be sufficient to eliminate off-site migration but not too great to draw oxygen into the waste. Excess oxygen in the waste can cause subsurface landfill fires. Operation of a LFG collection system tends to be an art rather than a science. Each wellhead is monitored for vacuum, oxygen and methane content. The valves on the wellhead are then adjusted accordingly to maximize the system and comply with regulatory requirements.

4.2 Markets for Recovered Products

LFG utilization approaches can be grouped into the following categories:

- Incineration
- Low Btu gas
- Medium Btu gas
- High Btu gas
- High Btu gas with carbon dioxide recovery
- Chemical products recovery

Each option is based on gas quantity, composition, system reliability, costs, revenues and risks.

4.2.1 Incineration

Incineration is a control measure for LFG that is common in areas where LFG control is needed but, because of market conditions, other utilization is not cost effective. Typically, incineration is conducted in a flare system where LFG is flared in an enclosed tube. Also, many other utilization technologies have a flare system to handle excess LFG (beyond the capacity of the primary device) and to use during malfunction or service of the primary LFG control device. Flaring of the gas is the least costly option but may not be permitted in areas with poor air quality.

4.2.2 Low Btu Gas

Raw LFG contains significant moisture content and trace amounts of contaminants that limit the market for low Btu gas. Typically low Btu LFG is used for steam boiler fuel, for heating internal structures, or at facilities close to the LFG source (e.g., cement kiln). The utilization of this form of LFG is limited to markets close to the landfill. Little processing is required for converting LFG to low Btu gas. Primarily removing a majority of the moisture is required to utilize the gas as a low Btu fuel.

4.2.3 Medium Btu Gas

Medium Btu gas differs from raw or low Btu gas by processing the gas utilizing compression, refrigeration and chemical processes to remove moisture and trace contaminants from the LFG. Utilizing gas “clean up” processes yields a relatively clean, dry gas suitable for other uses.

Partially cleaned gas can be used for heating purposes at a nearby industrial plant or for electric generation in a reciprocating engine or turbine. Primarily power generation from medium Btu gas is completed through reciprocating engines, gas turbines, steam turbines or a combination of gas and steam turbines. Typically gas turbines are 23 percent efficient, reciprocating engines 28 percent efficient and combined gas and steam cycle turbines 35 to 40 percent efficient. Conversion of LFG to medium Btu gas typically is cost-effective if the gas is used for electric power generation.

4.2.4 High Btu Gas

High Btu gas includes the production of pipeline grade natural gas and separation of carbon dioxide for sale. The requirements to convertLFG to high Btu gas require separation, compression, moisture removal and cleaning of contaminants from the raw LFG. Refinement of LFG to this level is typically cost prohibitive. The cost to upgrade medium Btu gas to high Btu gas versus the expected sales value of high Btu gas versus medium Btu gas used in power generation typically makes the refinement of the gas cost prohibitive.

4.2.5 Chemical Products Recovery

LFG contains two primary components methane and carbon dioxide. These two components can be used as basic materials to manufacture chemicals like methanol. However, chemical products synthesized from LFG have not been pursued by the LFG developers. This is partially attributed to the cost to clean up LFG to obtain a product suitable for chemical synthesis.

4.3 Current Uses

Currently, LFG projects across the United States include grassroots-based, community driven initiatives to large corporate projects that utilize LFG to power large plants. The clearinghouse for most (if not all) LFG projects is the USEPA Landfill Methane Outreach Program (LMOP). LMOP is a voluntary assistance and partnership program that promotes using LFG as a renewable energy source. LMOP aids businesses, states, energy providers and communities to develop LFG products. LMOP also tracks the current LFG development projects and maintains a database of LFG projects.

Currently, existing LFG projects fall into four general categories: electricity, direct use, cogeneration and other. These projects will be discussed in detail in the following sections. LMOP also maintains a list of candidate projects. These projects are of a size that make them marginal from an investment standpoint, but offer other potential benefits that may entice investors to develop a LFG project.

4.3.1 Existing Projects

4.3.1.1 Electrical Generation

Electrical generation from LFG is conducted by providing some pretreatment of the gas (usually drying the gas to remove moisture and possibly some purification to remove contaminants) followed by combustion to produce electricity. LMOP reports 273 separate projects producing electricity from LFG. The project breakdown by type is:

Type	No.	
Reciprocating Engine	210	(77%)
Gas Turbine	31	(11%)
Microturbine	13	(5%)
Steam Turbine	9	(3%)
Combined Cycle	6	(2%)
Stirling Cycle Engine	2	<1%)
Utility Boiler	1	<1%)
Fuel Cell	1	<1%)

By far the most common practice is to use reciprocating engines to combust the LFG that drives a generator to make electricity. This technology is well developed with several suppliers of LFG engine setups including Ingersoll-Rand Energy Systems, Jenbacher Ltd, Waukesha Engines – Dresser and Caterpillar. Other technologies, such as microturbines and sterling cycle engines, are beginning to develop on smaller projects or projects where air emissions requirements may not support a traditional reciprocating engine. New technology includes the fuel cell. A fuel cell project in Braintree, Massachusetts, develops 0.2 MW of electricity using a fuel cell adapted for use with LFG.

In Minnesota, LMOP has four LFG to electricity projects listed as active. Three projects—WMI-Burnsville, WMI- Elk River and BFI-Flying Cloud—report using LFG to produce electricity with the use of reciprocating engines. WMI-Burnsville has a capacity of 4.2 MW; WMI-Elk River, 3.2 MW; and BFI-Flying Cloud, 4.8 MW. The fourth project is BFI-Pine Bend, which uses a combined cycle engine to produce 12 MW of electricity.

4.3.1.2 Direct Use

Direct use technology uses the raw LFG as a heat source for a boiler, heating device or greenhouse. Most direct use projects are close (if not on site) to the landfill. The LMOP program lists 71 direct use projects for LFG in the United States. An example of a direct-use LFG project is the Scott County Landfill in Davenport, Iowa. LFG is extracted from an old closed landfill area and used as a heat source for cement kilns at a neighboring plant. This type of use of LFG can be very cost-effective since capital costs for electrical producing engine and generator sets and associated switch gear to transfer power to the grid are avoided with direct use of the LFG. Additionally, the costs to purchase natural gas are avoided by using LFG as the fuel source for the cement kiln process.

4.3.1.3 Cogeneration

Cogeneration facilities use LFG to generate electricity and thermal energy (e.g., steam or hot water). LMOP reports nine cogeneration facilities in the United States. These types of project increase the efficiency of the system but require a near by end user of the thermal energy to be viable. A typical cogeneration process would be LFG used in a turbine to produce electricity. The turbine exhaust is then used as a heat source for a boiler or for heating nearby facilities.

4.3.1.4 Other

Other uses for LFG are alternate vehicle fuels, pipeline quality high and medium Btu fuel and methanol production. LMOP reports 29 projects in the “other” category. Eighteen of the projects use LFG in a flare system to evaporate leachate. Nine projects convert the LFG to a high Btu pipeline quality gas and one project at the Los Angeles CountySanitary District uses LFG as a vehicle fuel for small vehicles (pickups and cars) operating at the landfill.

4.4 Waste Stream Applicability

The waste stream for Ramsey/Washington counties is of the content to develop a substantial LFG project but only after an initial waste placement of 2 to 3 million tons. This would supply enough LFG to support development of a LFG project. The LFG conversion method used would be selected based on site conditions, location of end uses, location of power grid access, agreements and economics. The lack of federal or state tax credits would make funding a private independent project difficult. Without tax credits, there is little benefit to a private contractor working for Ramsey/Washington counties to install a LFG system prior to regulations requiring such a system. Thus, in-place waste would need to exceed 2.76 million tons before a LFG system would be required. However, viability of a LFG conversion technology may require more in-place waste to be cost effective.

4.5 Permitting/Regulatory Issues

For LFG development projects, the primary regulations of concern are air pollution regulations. The primary air regulation for landfills is the New Source Performance Standards that are contained in 40 CFR Part 60 subpart WWW. These regulations require active LFG collection and control for all MSW landfills, with in-place waste of 2.5 million megagrams (2.76 million tons) or 2.5 million cubic meters (3.27 million cubic yards). The regulations require specific LFG control to reduce emission of greenhouse gases, like methane. It is also likely that the site will be subject to Title 5 air permitting. Title 5 requires quantification of all sources of air pollution at a facility. Fees for the Title 5 permit are charged based on the tons of pollutants discharged into the air each year.

4.6 Applicability to Ramsey/Washington Counties’ Waste Stream

From the waste stream quantity and quality data, it is apparent Ramsey/Washington counties generate enough MSW to make a LFG project cost effective. However, LFG recovery is not a “stand alone” process. For a LFG project, a landfill would be required. Furthermore, landfilling would need to occur for approximately five years before regulations would require installation of an active LFG collection and control system. Use of bioreactor technology would increase LFG generation, which may provide more opportunities for energy recovery from LFG. Leachate recirculation would have a similar effect but would not be as effective as bioreactor technology.

5. Summary

The objective of this report was to provide the current state of the practice for three technologies: (1) bioreactor landfills, (2) leachate recirculation, and (3) landfills with methane recovery. Each technology is described, markets for recovered products analyzed, and current uses identified. The applicability of the technology to the Ramsey/Washington counties' waste stream and permitting and regulatory issues were also discussed.

Bioreactor landfills are the current emerging technology in landfilling. Using liquids (including leachate and gas condensate) to optimize waste moisture has several advantages. The advantages of increased airspace of up to 30 percent, more LFG production, and avoidance of leachate disposal costs all make bioreactor landfill technology appealing to landfill operators. However, bioreactor landfill technology does require additional capital investment over conventional landfills. For Ramsey/Washington counties, bioreactor landfill technology would currently need to be employed at an out-of-state landfill. Current Minnesota regulations allow bioreactors landfills, but MPCA is in a "wait and see" mode regarding bioreactor landfills and leachate recirculation.

Landfills that utilize leachate recirculation are similar to bioreactor landfills. Leachate recirculation alone may not provide sufficient moisture to fully degrade organics like bioreactor landfills, but increased gas production and settlement can be expected. In addition, leachate recirculation is currently permitted at a large scale in several states. For Ramsey/Washington counties, a landfill that employs full-scale leachate recirculation currently requires disposal out of state. The MPCA currently only permits "pilot-scale" leachate recirculation projects at select landfills.

Landfills with methane recovery is a natural addition to a bioreactor landfill or leachate recirculation landfill. LFG recovery and conversion to electricity is a well-developed technology and can be cost effective for large projects or where tax incentives are available. The four methane recovery projects in Minnesota demonstrate that landfills with methane recovery are viable. However, this is not a stand-alone system and Ramsey/Washington counties would first need to develop a landfill to utilize this technology.

Finally, this report was developed to help educate policy makers on these three technologies and how these technologies could be applied to Ramsey/Washington counties. To a certain extent, the technologies are a "subset" of the previous technologies (i.e., bioreactor landfills would include both leachate recirculation and methane recovery). Each of the technologies include all the inherent engineering, operational, and financial assurance features of modern sanitary landfills, which are fundamentally different from the early landfills found to contaminate groundwater. But beyond this, bioreactor landfills have the potential to:

- Speed the decomposition process of the wastes such that the generation of leachate and landfill gas occurs sooner rather than being delayed until some time longer in the future when liners and covers have had more time to fail.

- Significantly reduce potential long-term environmental consequences of landfilled wastes.
- Save landfill space.
- Improve leachate treatment and actually reduce the toxicity of the leachate.
- Enhance landfill gas production so that it can be more effectively recovered and utilized beneficially.
- Reduce the length and cost of post-closure activities.
- Cost no more per ton than current Subtitle D landfills ($20 to $30 per ton).

Ramsey/Washington counties' officials should learn more about these technologies, how they differ from early landfills, and how a bioreactor landfill could fit into future solid waste management practices. Activities to increase familiarity with the bioreactor landfill technology could include discussions with professionals active in the industry and site visits to existing facilities. Ramsey/Washington counties can then consider the potential advantages and disadvantages of bioreactor landfills along with other available options for managing solid wastes. Bioreactor landfill technology could be fully compatible with current recycling, source-separated organics recovery, and existing waste-to-energy facilities. Bioreactor landfill technology is an emerging technology that some day could be used to manage MSW not handled higher on the waste management hierarchy.