APPENDIX C

CASE STUDIES

OF

BIOREACTOR LANDFILL PERFORMANCE

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Six case studies of bioreactor landfill research and demonstration projects were presented in the Workshop by state government, local government, academia, and private industry:

- Sandtown, Delaware – Delaware Solid Waste Authority (DSWA)
- Florida Bioreactor Landfill Demonstration Project, New River Regional Landfill – University of Central Florida
- Environmental Protection Agency (EPA) eXcellence and Leadership (XL) project – Yolo County, California
- Worcester County, Maryland – EA Engineering Science & Technology
- Outer Loop Landfill Bioreactor Studies, Louisville, Kentucky – Waste Management, Inc. (WMI) and the EPA
- Williamson County, Tennessee – Environmental Control Systems, Inc., and Civil and Environmental Consultants.

The following sections briefly describe these case study presentations.

C.1 SANDTOWN, DELAWARE – DELAWARE SOLID WASTE AUTHORITY

The DSWA conducted a Test Cell Program in association with the EPA. This program began in 1987 and tested a number of different liners and landfill systems. Site conditions throughout Delaware consist of high groundwater and sandy soils so locally available cover materials have high permeability.

Two double-lined test cells were constructed and filled with household waste; four different liners were tested. Flumes were constructed for stormwater control and measurement. Groundwater monitoring wells were also installed.

Test Cell 1 was constructed and operated as a wet cell. A leachate recycling field was installed over the first waste lift. The drainage layer consisted of 2 feet of sand. Recirculation lines connected to a storage tank system.

Test Cell 2 was a dry cell. A geotextile was used for the drainage layer. Two collection system types were installed: with and without piping. Results found that the use of piping was preferable.

There were concerns about hydraulic head buildup on the liner system. However, they were unable to measure the hydraulic head, so it was believed to not exceed more than 1 foot.

The goals of this study were to compare dry and wet landfills (i.e., typical landfill and bioreactor), and to conduct a full-scale test of a bioreactor landfill. The following aspects were monitored and compared:

- Leachate generation rates – more leachate was generated during dry cell operation than in the wet cell. This was possibly the result of permeability differences in the daily cover. After the final cover was installed on both cells, leachate generation rates became very similar, but the decomposition rate in the wet cell ended up being twice that experienced in the dry cell.

- Leachate characteristics – leachate from both cells was very similar during the operational period. Chemical oxygen demand (COD) was greater than 10,000 mg/L in the first year. After the final cover was installed 5 to 6 years later, COD significantly decreased to 500 to 700 mg/L in the wet landfill, and to approximately 200 mg/L in the dry cell.

- Moisture levels in the test cells – this proved difficult to measure. Lysimeters were installed in the waste and in the wells, but the data obtained may be questionable. This points to the need for a reliable technique to measure moisture level.

- Landfill gas generation rates – the sandy nature of the cover materials made it difficult to measure gas generation rates as well as was desired. However, results indicated that gas generation in the wet cell was about an order of magnitude higher than in the dry cell.

- Landfill gas characteristics were very similar between the two cells with methane consisting of about 50 percent of the gas.

- Leachate recirculation system performance – limited data were available because such a small leachfield was used (50 feet by 50 feet) on top of the cell. These tests relied on horizontal rather than vertical liquid addition.

- Liner performance – four types of liners were studied. These liners were tested before and after use in the test cells. No significant deterioration of any kind was found.

- Capping system performance – first a soil cap was tried, then a partial cap was placed on top, and finally side slopes were capped with polyethylene. Only a few inches of settlement were seen. However, the scale of the test was not large enough to draw conclusions from the data.

The test included a simulated cap failure on the dry test cell. Once leachate characteristics demonstrated decreased COD, an area of the cap was opened and several thousand gallons of water were added over a few weeks. Leachate changes were monitored during and after water addition. The study found that the added water took about 45 days to reach the collection system, at which time the leachate COD increased to about 30,000 mg/L. This result indicated that a real concern for future performance of a landfill includes re-initiation of the bioreaction process following cap failure.

Types of alternative daily covers tested included tarps and spray foam.

The final soil cover had a permeability of $1x10^{-4}$ cm/sec. After placement, there was a significant amount of leachate generated; in some cases, more leachate was generated than could be used for recirculation.

Other cover types tested included:

- Astroturf placed over used carpet with tires used to hold down the material resulted in a slight, insignificant reduction in leachate production. Significant side slope penetration by liquids was experienced with this approach.

- Polypropylene (black) was laid on the side slopes and reduced leachate generation by an order of magnitude.

Late in the study, the test cells were opened and the waste excavated to determine the results of decomposition. The organic decomposed material represented more than 50% of the waste mass (by weight) in the wet cell, while the same material was less than 50% of the waste mass (by weight) in the dry cell.

Landfill mining was also examined in another study. The leachate collection system in another wet landfill (built in 1980) experienced a decline in leachate removal requiring excavation into the cell to determine the nature of the problem and make repairs. This landfill had a polyvinyl chloride (PVC) liner and the leachate collection system consisted of septic pipe wrapped with geotextile. Upon excavation, it was determined that the septic pipe was crushed by the weight of the landfill waste and the geotextile had severe biofouling.

Upon excavation, the waste mass was found to be very moist in some areas and dry in others, but no gushing liquid was encountered. A crude vertical recirculation system was found within the waste mass that contributed to the moisture differences encountered.

Waste material was screened upon excavation. The fines were used for daily cover. Instances were encountered where waste within plastic bags showed no decomposition whatsoever (e.g., 10 year old green grass). This finding indicated that leachate was not distributed within the landfill as well as was desired.

The decomposed waste resembled soil or compost. The nondecomposed material was contaminated by leachate and was therefore unsuitable for recycling or other reuse.

Test program conclusions included the following:

- If properly designed and constructed, bioreactor landfills are attractive alternatives to conventional landfills

- Use of tarps or foam for daily cover is promising

- Use of polypropylene for capping and liner is promising

- Geonets are preferable for leachate collection systems

- Trommeling is the preferred processing method for landfill mining

- The most useful recycled product mined from the landfills is daily cover, which has high costs but may be appropriate for certain applications.

C.2 FLORIDA BIOREACTOR LANDFILL DEMONSTRATION PROJECT, NEW RIVER, FLORIDA – UNIVERSITY OF CENTRAL FLORIDA

The Florida Bioreactor Landfill Demonstration Project has the following objectives:

- Demonstrate full-scale use of bioreactor technology
- Evaluate aerobic bioreactor technology
- Compare aerobic and anaerobic processes
- Control and measure all inputs and outputs.

The Florida Department of Environmental Protection is the primary funding source for this project.

The landfill for this demonstration consists of the following:

- Three cells with a composite liner

- Leachate collection in one cell consists of sloped geomembranes; no piping is used

- Recirculation of leachate and air in two of the cells

- Leachate/air injection conducted through well clusters on 50 foot spacings and drilled to various depths

- Permeable daily cover (10^{-5} cm/sec).

This is a retrofit because 75 feet of waste are already in place. Wells will be installed into the existing waste mass using direct push technology as well as a new version of air-driven rotary drill. This latter technique drilled very rapidly, but it was harder to take samples.

Gas will be collected from the leachate collection system and from beneath the landfill cap using positive displacement blowers to create a vacuum. Trenches will be placed below the cap to assist with gas collection. Collected gas will be brought to a flare and burned.

This study will measure the following:

- Leachate quantity and quality
- Landfill gas quantity and quality
- Waste properties
- Settlement.

Instrumentation will be placed to measure:

- Head on liner (using 128 pressure transducers outside the waste area)
- Leachate flow
- Landfill temperature
- Moisture content (through measured resistance).

Upon receipt of the final permit (estimated to be December 2000), construction should begin with recirculation beginning in 2001. A large quantity of liquid will be added, followed by addition of sufficient water over time to sustain the reaction. Groundwater and possibly stormwater runoff will be used to supplement leachate for water addition as insufficient leachate is anticipated to be generated. However, the State of Florida has put a ceiling on the amount of water allowed to be added.

C.3 EPA PROJECT XL – YOLO COUNTY, CALIFORNIA

Yolo County has a bioreactor landfill demonstration project under the EPA Project XL. This project involves a 725-acre landfill with a 25-million cubic yard capacity, a single composite liner system, leachate collection and removal, gas collection (with a co-located 2-megawatt power plant), and a 15-acre storage pond for water/leachate. The landfill opened in 1975 and closure is anticipated in 2021.

Previous research at this site addressed the following objectives:

- Demonstrate that water addition can substantially accelerate waste decomposition and landfill gas generation

- Monitor biological conditions in the landfill

- Estimate the potential for landfill life extension

- Better understand moisture movement in the landfill

- Assess performance of shredded tires as drainage material

- Provide data to EPA and the private sector

The landfill cells used in this early research had the following characteristics:

- Two test cells (control and enhanced)
- Double composite liner with leak detection
- Compacted clay sidewalls
- Manholes to collect leachate
- Vertical gas collection system.

Instrumentation was installed on 20- to 30-foot centers during waste mass emplacement. Clay levees are placed around the cells to isolate the gas collection and leachate systems from the rest of the landfill.

The cover consists of shredded tires placed on top of a geotextile layer with a clay layer over the tires. This technique creates a gas collection zone beneath the clay cover.

Approximately 470,000 gallons of water were added in a manner similar to drip irrigation over a two-year period. Injection points were on 20-foot centers and were each surrounded by shredded tires.

Waste samples were obtained by coring. Results indicated that good moisture distribution was achieved. However, the bottom portions of the landfill cells were generally found to be drier, which indicated that more water could have been added.

Gas generation was higher over time in the wet cell. Within one year, substantial decreases were seen in COD, total dissolved solids (TDS), and biological oxygen demand (BOD).

Findings from these earlier studies indicated that:

- Addition of water does promote the bioreaction resulting in accelerated decomposition and methane recovery

- Significant settlement and leachate chemistry improvement can be seen after a short time (within 6 months)

- Shredded tires perform well in support of landfill gas transfer and leachate injection.

Under EPA Project XL, Yolo County will be conducting a full-scale demonstration that builds on efforts conducted over the past 5 years involving many different funding sources. This demonstration project has the following goals:

- Accelerate waste decomposition
- Accelerate methane production and improve energy recovery
- Verify improvement in leachate quality
- Verify hydraulic head on the liner
- Look at both aerobic and anaerobic conditions

- Look at post-closure implications.

For this demonstration, groundwater will be used to supplement the leachate used to increase the moisture content of the waste mass. The liquid application rate will be about the same as for previous efforts – approximately 10 gallons per minute on a 100-foot by 100-foot area. This is roughly 13 million gallons of water for 400 tons of waste.

The daily cover will consist of shredded green waste and a tarp rather than soil.

The measurement system is quite extensive involving over 320 monitoring points in each landfill cell. A supervisory control and data acquisition (SCADA) system will be installed to manage the instrumentation and the data collection. Such an extensive instrumentation system is necessary to obtain the desired research data and to address concerns raised by regulatory agencies (such as potential head on liner). This can be very expensive – for example, 10 acres cost about $2 million to construct.

Yolo County hopes to demonstrate the following in this project:

- Extended use of current site and reduced need for a new site
- Amount of gas that can actually be recovered for economical energy use
- Landfill mining opportunities and landfill cell reuse
- Improved leachate quality and reduced risk of groundwater contamination
- More rapid biodegradation and earlier stabilization of the waste.

The methane generation is a particular issue for this site. The production of electricity using the methane generated by the landfill results in higher NOx emissions. This is a concern because the landfill is located in a nonattainment area for air emissions regulation and control.

Federal approval to begin water addition is anticipated to occur in November 2000 with cover system installation completed by February 2001 and liquid and air injection beginning April 2001. Data collection and reporting is expected to continue from July 2000 to July 2004.

C.4 WORCESTER COUNTY, MARYLAND – EA ENGINEERING SCIENCE & TECHNOLOGY

This demonstration project has been ongoing for about 9 years at an operating county landfill that receives approximately 300 tons per day of municipal solid waste. Recirculation began once the first lift of waste was emplaced and has continued throughout the life of the landfill.

Such bioreactor landfills represent solid waste treatment rather than disposal, and involve the following:

- Long-term risk reduction
- Leachate treatment through recirculation
- Maximization of airspace through accelerated decomposition

- Long-term risk reduction through source treatment
- Closure and post-closure cost savings.

In addition, landfill mining in conjunction with the above can offer significant benefits.

This location receives 41 inches of rain a year so there is no lack of liquid. The landfill consists of four cells, each about 17 acres with a 400,000-gallon aboveground storage tank to support recirculation through vertical recharge wells placed on 150-foot centers. This approach to liquid injection was selected to keep these activities out of the way of daily operations. Leachate was recirculated without any additional treatment or modification.

Data collected between January 1991 and July 1997 showed the following:

- BOD dropped briefly after liquid addition, then peaked, then sharply declined to achieve baseline levels in about 18 months

- New waste addition resulted in BOD variation (increases)

- Fatty acid production increased and caused the pH to rise

- pH changes significantly reduced the metal-carrying capacity of the leachate with iron and chromium no longer coming out into solution

- Chlorinated volatile organic compounds (VOCs) significantly declined from 17 times the maximum contaminant level (MCL) to below the levels specified in the Safe Drinking Water Act, becoming nondetectable after about 3 years

- Certain gasoline constituents did not disappear and had variable but consistent presence, possibly from household hazardous waste and equipment operation in the landfill cell.

These data indicate the following measures of the process rate for bioreaction completion:

- From BOD data – reaction completed in 4 years
- From the generation of insoluble metal complexes – reaction completed in 3 years
- From the chlorinated VOCs reaching baseline levels – reaction completed in 3 years.

This project involved constant recirculation resulting in approximately two-thirds of the leachate generated over 8 years being recirculated. In western and southwestern United States areas, possibly all leachate can be recirculated.

Quantification of the overall water balance was conducted including consideration of the following:

- All incoming waste moisture
- Preferential flow paths through the waste

- Difficulties achieving even moisture distribution
- Runoff
- Evapotranspiration
- Infiltration
- Waste field capacity
- Average waste receipt.

The water balance indicated the potential for 100 percent recycle of the leachate.

This recirculation process has been operated since 1990. Recently, the feasibility of landfill mining was examined and the utility of the remaining materials was evaluated for on-site and off-site uses. This investigation was conducted using a rotary trommel with 1-inch holes. The material removed resembled soil fines and represented approximately 75% of the material removed except in the top 25 feet of the waste mass. Little degradation was encountered in that zone and is believed to be due to uneven waste wetting.

The humus-like material recovered in this excavation appeared suitable for use as a landfill cover and nonlandfill uses might be possible. The reclaimed material had hazardous constituents present at two to three orders of magnitude below the levels that would trigger classification of the material as a hazardous waste. The reclaimed material met all human health risk-based limits for industrial use, and met all requirements for residential reuse except for arsenic limits.

A life cycle cost analysis was also developed. The scenario used in this analysis was to build one cell to hold unusable residuals from material recovered out of six original cells. All undegraded materials would go back into an active landfill cell. No caps are used because each cell keeps getting reworked. This analysis estimated a landfill life of 50 to 60 years.

Key conclusions drawn from this study are:

- There is potential for long-term savings in reduced monitoring

- Significant reduction of long-term risk to the environment

- Offsite use of recovered, decomposed material can double the landfill site life if properly operated.

C.5 OUTER LOOP LANDFILL BIOREACTOR STUDIES, LOUISVILLE, KENTUCKY – WMI AND EPA

WMI has been evaluating landfill bioreactor technology at sites across the United States. WMI and EPA have developed a Cooperative Research and Development Agreement (CRADA) for joint bioreactor landfill research. Bioreactor research studies planned for the Outer Loop Landfill are anticipated to be among the first studies under this agreement.

Over the next 2 years, WMI will be looking at aerobic, anaerobic, and facultative bioreactor landfills as compared to conventional municipal solid waste landfills. This research effort is anticipated to be large enough and long enough to evaluate the economic and operational issues, especially the health and safety aspects of bioreactor operations. This effort involves statistically based studies to generate credible data.

The waste area at the Outer Loop Landfill is 400 acres. Each test and control cell involves about 6 acres.

The operation of an aerobic-anaerobic landfill bioreactor will cause rapid biological decomposition of easily degradable waste in the aerobic stage. This bioreactor landfill will be constructed during waste placement and will have separate, dedicated leachate and gas collection systems.

The objectives of the aerobic-anaerobic bioreactor study are to:

- Evaluate waste stabilization enhancement resulting from sequential establishment of aerobic and anaerobic conditions relative to waste stabilization in the control cells

- Demonstrate the feasibility of implementing this technique in a commercially viable operating scale.

The facultative landfill bioreactor study intends to demonstrate control of nitrogen cycling in the landfill. Ammonia-containing leachate will be treated external to the landfill by nitrification to convert the ammonia to nitrate. The treated leachate will be introduced to a landfill cell where the nitrate will be used by facultative bacteria. This approach is expected to reduce the buildup of ammonia in the leachate, but may also reduce methane production. Trenches will be used for liquid infiltration and there will be separate leachate and gas collection systems.

The objectives of the facultative bioreactor study are to:

- Evaluate stabilization enhancement resulting from nitrate-enriched leachate application
- Assess commercial viability of the operation.

Both studies will include replicate sampling and analysis. The studies will characterize:

- Landfill gas and emissions
- Leachate head on liner
- Leachate production rates
- Waste temperature (daily)
- Waste settlement (quarterly)
- Volatile solids (annual)
- Biochemical methane potential (annual)
- Moisture content (annual)
- Waste density (annual)

- pH (annual).

Critical measures will be:

- Continuous gas production rates
- CO_2, CH_4, O_2, and balance concentrations (daily).

Noncritical measures include:

- Nonmethane organic compounds (NMOCs) (quarterly)
- Hazardous air pollutants (HAPs) (quarterly)
- Surface emissions (twice per quarter)
- Cellulose:lignin ratio (annually)
- Carbon:nitrogen ratio (annually).

Project startup is anticipated for October 2000.

C.6 WILLIAMSON COUNTY, TENNESSEE – ENVIRONMENTAL CONTROL SYSTEMS, INC., AND CIVIL AND ENVIRONMENTAL CONSULTANTS

The Williamson County landfill has a 6-acre footprint, a waste depth of approximately 40 feet, and nearly 70,000 tons of solid waste. This landfill is located in a rural site without access to a publicly owned treatment works (POTW). The cell shape resembles a truncated pyramid with steep slopes and is lined with Subtitle D composite liner and an underdrain leachate collection system. Current head on the landfill liner averages less than one inch. The landfill cover consists of 12 to 24 inches of highly compacted cover soil and 6 to 24 inches of mulch.

The waste mass had the following characteristics (based on initial characterization and sampling data):

- 29.7 percent average in-situ moisture content
- 71°F average temperature
- Average oxygen content of the gases ranging from 6 percent to 11.9 percent by volume
- Estimated biodegradable organic fraction of 6,900 tons
- 15:1 carbon to nitrogen ratio.

The objectives of this study include evaluation of the following:

- Changes in waste characteristics following operation of the bioreactor
- Effectiveness of proposed air and leachate delivery systems
- Overall trend in leachate quality and quantity
- Variations in methane gas production
- Overall economic costs versus benefits
- Site water balance
- Impacts of bioreactor operation on stability of waste fill.

Lysimeters, tensiometers, and other instrumentation were installed to collect the data needed to develop a full site water balance. The estimated water balance indicated that 3.8 million gallons of water were needed to achieve a 40% moisture content; this represents approximately 54 gallons of water per cubic yard of waste. There is an on-site weather station including a data logger to continuously collect weather data, which can be compared with water level studies.

Liquid is added at 30 gallons per minute. Wells (over 200 with over 190 thermocouples) were placed on a 50-foot grid and nested at 10, 20, and 30 feet. Because this was a retrofit to an existing landfill, a 10-foot safety factor was included in the drilling operations to avoid penetrating the lower liner. Water sources include leachate from the landfill and storm water. Other water sources may be necessary to obtain sufficient quantities.

The liquids are aerated in an aboveground mixing tank prior to circulation in the landfill via an aboveground pipe network.

Air is added to the waste mass. When blowers are operating, three readings of CO2, O2, and methane are taken weekly from each of 12 monitoring wells.

Waste cellulose:lignin ratio readings are taken quarterly. Biochemical Methane Potential (BMP) testing is currently underway to further examine the biodegradation process.

Other measurements include:

- Quarterly sampling of solid waste and leachate
- Nutrient content within the waste (with supplemental nutrients added as necessary)
- Air injection amounts and and leachate quantities injected and collected;
- Weekly inspection of leachate head on liner.

The initial theoretical water balance calculations indicate that biological processes, especially in zones that become aerobic, should biochemically produce a significant amount of the water to help support the bioreaction process. Data collected from lysimeters during heavy rainfall events indicated that infiltration is slope dependent. Good saturation was found in flat areas—the greater the slope, the less inflow.

The following geotechnical research is planned using data collected from this landfill:

- Whether failure planes are created in the waste mass from injection of so much liquid?
- What is the settlement rate?
- Temporal and spatial changes in head on liner.

There are also plans to conduct slope stability analysis and to use this data to develop estimates of waste mass strength.