U.S. EPA PROJECT XL: YOLO COUNTY'S ACCELERATED ANAEROBIC AND AEROBIC COMPOSTING (FULL-SCALE CONTROLLED LANDFILL BIOREACTOR) PROJECT

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ABSTRACT

The County of Yolo Planning and Public Works Department (Yolo County), will operate its next 20-acre landfill module near Davis, California as a controlled bioreactor landfill to attain and demonstrate a number of environmental and cost savings benefits in a full-scale landfill operation. As part of this project, Yolo County is requesting that the EPA grant regulatory flexibility from the Resource Conservation Recovery Act (RCRA) prohibition in 40 CFR 258.28 regarding Liquid Restrictions, which may preclude addition of useful bulk or non-containerized liquid amendments. Yolo County is also requesting flexibility in state regulatory requirements for bottom linings based on project performance, available controls, and environmental safeguards which have been demonstrated in their smaller-scale 9000-ton test program at the Yolo County Central Landfill. In the first phase of this 20-acre project, a 12-acre module has been constructed. This 12-acre module contains one 9.5-acre cell, which will be operated anaerobically and a 2.5-acre cell aerobically.

Co-sponsors of the project with Yolo County are the Solid Waste Association of North America (SWANA) and Institute for Environmental Management (IEM, Inc.). The County is proposing to supplement the liquid addition with groundwater and leachate, but would like to obtain the flexibility to possibly utilize other liquids such as gray-water from a waste water treatment plant, septic waste and food-processing wastes that are currently land applied. Liquid wastes such as these, that normally have no beneficial use, may instead beneficially enhance the biodegradation of solid waste in a landfill for this project.

INTRODUCTION

Sanitary landfilling is the dominant method of solid waste disposal in the United States, accounting for about 217 million tons of waste annually (U.S. EPA, 1997). The annual production of municipal solid waste in the United States has more than doubled since 1960. In spite of increasing rates of reuse and recycling, population and economic growth will continue to render landfilling as an important and necessary component of solid waste management.

In a Bioreactor Landfill, controlled quantities of liquid are added, and circulated through waste as appropriate. The purpose is to accelerate the natural biodegradation and composting of solid waste. This process significantly increases the biodegradation rate of waste and thus decreases the waste stabilization and composting time (5 to 10 years) relative to what would occur within a conventional landfill (30 to 50 years, or more). If the waste decomposes (i. e., is composted) in the absence of oxygen (anaerobically), it produces landfill gas (biogas). Biogas is primarily a mixture of methane, a potent greenhouse gas, carbon dioxide, and VOC's, that are local air pollutants. Methane is also a fuel. This by-product of anaerobic landfill waste composting can be a substantial renewable energy resource that can be recovered for electricity or other uses. Other benefits of a bioreactor landfill composting operation include increased landfill waste settlement and therefore increase in landfill capacity and life, improved opportunities for treatment of leachate that may drain from fractions of the waste, possible–reduction of landfill post-closure efforts, landfill mining, and abatement of greenhouse gases through highly efficient methane capture over a much shorter period of time than is typical of waste management through conventional landfilling.

DESCRIPTION OF THE FACILITY

The Yolo County Central Landfill (YCCL) is an existing Class III non-hazardous municipal landfill with two Class

II surface impoundments for disposal of selected non-hazardous liquid wastes. This site encompasses 722 acres and is owned and operated by Yolo County. The YCCL was opened in 1975 for the disposal of non-hazardous solid waste, construction debris, and non-hazardous liquid waste. Existing on-site operations include an eleven-year old landfill methane gas recovery and energy generation facility, a drop-off area for recyclables, a metal recovery facility, a wood and yard waste recovery and processing area, and a concrete recycling area.

PURPOSE OF THE U.S. EPA XL PROJECT

A national pilot program called Project XL, which stands for "eXcellence and Leadership", allows state and local governments, businesses and federal facilities to develop with EPA an innovative strategies to test better or more cost-effective ways of achieving environmental and public health protection.

Through the EPA Project XL the data will enable EPA and State of California regulatory agencies to develop or modify regulatory requirements for such projects and therefore lead to commercialization of this technology. Yolo County is in the process of obtaining regulatory flexibility from the federal and state regulatory agencies. This approval is based on project performance, available controls, and environmental safeguards which have already been demonstrated in Yolo County's smaller-scale demonstration project at the Yolo County Central Landfill

This project will demonstrate three main objectives**:**

a) Acceleration of waste decomposition and leachate treatment, via liquid amendments and recirculation through pipe network serving the waste mass and demonstrate that this could be accomplished without excessive leachate head build up over the base liner. The goal is to accomplish rapid completion of composting, stabilization and generation of methane to the maximum practical yield.

b) Efficient capture of nearly all generated methane, withdrawn at slight vacuum from a freely gas-permeable shredded tire collection layer beneath low-permeability cover, without impacting local air quality. Near-complete extraction with this approach has already been demonstrated in the 9,000-ton small-scale demonstration cell at the Yolo County demonstration project.

c) Document the capital and operations cost of a full-scale bioreactor and determine the economic viability of its commercialization.

STALKEHOLDER INVOLVEMENT AND SUPPORT

Stakeholder involvement and support for this concept has already been demonstrated by previous federal, state, and local support of this bioreactor concept. For example, in 1994, the Yolo County Planning and Public Works Department initiated a bioreactor landfill demonstration project to evaluate the Bioreactor Landfill concept for its Central Landfill near Davis, California. The construction phase of the project was funded by Yolo and Sacramento Counties ($125,000 each), the California Energy Commission ($250,000), and the California Integrated Waste Management Board ($63,000). More recent grant funding for the monitoring phase of the project has been received from the U. S. Department of Energy through the Urban Consortium Energy Task Force ($110,000), and the Western Regional Biomass Energy Program ($50,000). Greenhouse gas and emission abatement cost-effectiveness studies have recently been completed with $48,000 in support from the National Energy Technology Laboratory (NETL). Further support, $462,000 recently committed by NETL, is enabling operation of the test cells for approximately 2 more years as well as helping prepare for larger module operation.

In addition, on January 26, 2000 the California Integrated Waste Management Board committed Yolo County $400,000 for the construction and testing of the full-scale bioreactor demonstration project.

Concerning local support for this XL project, Yolo County has held several public meetings for the full-scale demonstration project. These meeting have been held during the regular Waste Advisory Committee meetings to locate potential members of the local stakeholder group in addition to special stakeholders meeting. The County will convene periodic meetings of the stakeholder group to obtain comments on this proposal, as well as to brief the group on their progress during the duration of the XL agreement.

DESIGN AND OPERATIONS OF THE MODULE D FULL-SCALE LANDFILL BIOREACTOR

Yolo County proposes to operate its next full-scale 20-acre landfill module (Module D) with both anaerobic and aerobic bioreactor areas (also termed modules below). In the first phase of this 20-acre project, a 12-acre module has been constructed. One 9.5-acre cell will be operated anaerobically and the other 2.5-acre cell aerobically. The anaerobic and aerobic design and operations are summarized below:

Under current plans, the first phase of Module D will be further subdivided into the two independent bioreactor systems, the aerobic system and the anaerobic system. Module D was designed and constructed in a ridge and swale configuration to optimize landfill space and to maintain good drainage for the collection system. The blanket drainage layer slopes at 2% inward to two central collection v-notch trenches. Each of the trenches drain at 1% to their prospective leachate collection sumps located at the south side of the module. Phase 2 of Module D will also be constructed in a similar manner as Phase 1 of Module D.

Leachate Collection and Removal System (LCRS) Components

The prescriptive liner for Class III landfills consists, from top to bottom, of an operations/drainage layer capable of maintaining less than one foot of head over the liner, a 60-mil high density polyethylene (HDPE) liner, and 2 feet of compacted clay ($k < 1 \times 10^{-7}$ cm/sec).

The Module D liner and leachate collection system consists, from top to bottom, of a 2 foot thick chipped tires operations/drainage layer ($k > 1$ cm/sec) over 6 inches of pea gravel, a blanket geocomposite drainage layer, a 60-mil HDPE liner, 2 feet of compacted clay ($k < 6 \times 10^{-9}$ cm/sec), 3 feet of compacted earth fill ($k < 1 \times 10^{-8}$ cm/sec), and a 40 mil HDPE vapor barrier layer. The chipped tire operations layer was not placed during construction but will be placed immediately before waste placement.

The permeability of the clay liner, as constructed, was on the average about 6×10^{-9} cm/sec and the earth fill averaged about 1×10^{-8} cm/s. These two layers in effect provide a 5 foot thick composite liner. This fact, coupled with the lower permeability, will result in a significantly more effective barrier to leachate migration than the prescriptive liner system.

The liner system within the collection trenches and sump areas was upgraded further to a double composite liner to minimize potential leakage in these critical collection areas where head on the primary liner will be at its greatest. The liner and leachate collection system in the collection trenches and sumps consists from top to bottom of a minimum of 2 feet of gravel drainage material, a protective geotextile, a blanket geocomposite drainage layer, a primary 60-mil HDPE liner, a geosynthetic clay liner (GCL) ($k < 5 \times 10^{-9}$ cm/sec), a secondary 60-mil HDPE liner, 2 feet of compacted clay ($k < 6 \times 10^{-9}$ cm/sec), a minimum of 0.5 feet of compacted earth fill ($k < 1 \times 10^{-8}$ cm/sec), and a 40-mil HDPE vapor barrier layer. The thickness of the compacted earth fill actually varies from a minimum at the south end of the trench of 0.5 feet to a maximum of about 2.5 feet at the upper, north end of the leachate collection trench. Leachate collection pipes were also placed in the collection trench and at other locations on top of the primary liner to transport leachate immediately to the sumps for recovery, removal, and recirculation, as needed.

LCRS and Liner Performance

As described above, the more rigorous Module D LCRS and liner system is intended to outperform the California regulations, Title 27 and Subtitle D prescriptive liner. The leachate collection and recovery system (LCRS) has been designed and constructed to be free-draining throughout the life of the module and will maintain less head over the primary liner system than prescribed by Title 27 and Subtitle D.

The LCRS system has been constructed with a geocomposite layer, which has over 10 times the required capacity and will maintain the head over the liner system to less than 0.3 inches during liquid application periods. In addition, the chipped tire layer will provide a level of redundancy in the event that the geocomposite becomes clogged or otherwise nonfunctional.

In addition to the upgraded LCRS, the primary composite liner is in excess of the Title 27 prescriptive system. This is based on the reduced permeability (k) of the clay soil used during construction of the module. The permeability of the clay soil used in construction of the Module D liner is significantly lower than the prescriptive 1×10^{-7} cm/sec. Based on the results of the laboratory testing performed during construction of Module D, the clay liner has an average permeability on the order of 6×10^{-9} cm/sec. Using standard leakage rate analyses by Giroud et al. (1989), the leakage from the Title 27 system (with one foot of head over a HDPE geomembrane and 1×10^{-7} cm/sec clay liner) would be 1×10^{-4} gallons per minute from a standard 1 cm^2 hole in the liner. With the Module D liner (4 inches of head over a HDPE geomembrane and 6×10^{-9} cm/sec clay liner), the leakage would be 5×10^{-6} gallons per minute; less than 1/20 of the flow.

In the event that leakage were to occur through the 5-foot thick primary composite liner, the 40-mil HDPE liner would provide a secondary containment. Title 27 or Subtitle D does not require secondary containment for conventional landfilling operations. As constructed, the 40-mil HDPE liner will minimize further downward migration and aid in detection of migrating leachate. The 40-mil HDPE liner was sloped to mirror the primary liner. Geocomposite strip drains were also installed diagonally across the top of the 40-mil HDPE liner to act as drainage pathways to the southern portion of the cell located immediately beneath each of the leachate collection sumps. This will act as a vadose zone monitoring system for early detection of leakage across the entire Module D disposal area. This added feature provides another level of protection to the groundwater.

In addition, the County hired Leak Location Services (LLC) to locate any pinholes that could have been in the leachate collection trenches on the primary liner system.

LLC uses a high sensitive method using electrical charge to locate pinhole leaks very accurately. Using specialized equipment designed and built for locating liner leakage, LLC uses to verify integrity of liner system after completion of liner construction. Several small holes were found and repaired after this leak testing was done.

Liquid Addition Rate

For the anaerobic operation, it is estimated that the peak liquid addition, up to 10 gallons per minute (gpm) of liquid per 10,000 square feet (44 gpm per acre) of disposal area will be typically delivered to the waste once the module has reached its design height. Based on the demonstration cell performance the amount of liquid added would be in the range of 30 to 50 gallons per ton of waste. According to results of the bioreactor demonstration project by Moore et al.(1997), the average leachate generated during liquid introduction peaked at about 47% of the liquid delivery rate, which would equate to approximately 20 gpm per acre for the proposed program. Given a 9.5-acre drainage area, the total anticipated flow into any given sump would be approximately 190 gpm or 273,600 gallons per day.

For the aerobic operation, liquid will be added to waste at a faster rate since the aerobic reaction uses much of the water in the evaporation of liquid added. It is estimated that the total water evaporated will range between 200 to 400 gallons of water per ton of waste.

Based on the estimated leachate production, drainage into the leachate collection layer will be about 4.6×10^{-4} gpm per square foot of disposal area. It is approximately 200 feet between the ridge and collection trench. Using these values, the peak flow through the geocomposite will be about 0.09 gpm per linear foot of trench. The geocomposite for Module D has a measured capacity of 1.0 gpm per foot. Therefore, the geocomposite has over 10 times the capacity required under peak flow conditions.

Biological Clogging

Although clogging of the geocomposite layer is not anticipated, the LCRS has been designed under the conservative assumption that geotextile clogging may occur. In the event that the geocomposite were to become clogged or otherwise nonfunctional, the proposed chipped tire operations layer with its high porosity will provide adequate drainage. Due to the large particle size of the chipped tires (greater than 6 inches), the calculated effective permeability of the tire layer at the drainage slope of 0.02 is estimated to be well over 1.0 cm/sec. Given this value, it has a flow rate capacity on the order of 0.025 gpm per inch of thickness per one foot width. Therefore, at the calculated maximum inflow rate of 0.09 gpm per foot width, the head over the liner would not exceed 4 inches. Typically, collection systems are designed to maintain less than one foot of head over the liner. Therefore, this system has over three times the required flow capacity at the allowable prescriptive level of one foot.

SPECIALIZED DESGIN CONSIDERATION DURING OPERATION

Liquid Addition

Liquid will be applied during strategic periods to temporarily raise the moisture content of the waste to provide optimum conditions for rapid degradation and improved gas production. The duration of liquid addition will depend on when the optimum condition for rapid degradation has reached. The field data collected during the project will assist the County in determining the duration of liquid addition and recirculation. The total amount of liquid to be added will be measured and monitored as part of the liquid management program. This liquid will initially consist of a mixture of leachate and condensate from other landfill units and groundwater delivered through a series of pipes after an interim cover and gas collection system has been constructed to control landfill gas generated.

Gas Collection and Control

Early gas collection and control is necessary at bioreactor landfills because the site in essence is rapidly “aging” the waste so that it "behaves" as if it is much older. The result of this rapid "aging" is more complete biodegradation of the waste resulting in the generation of a larger quantity of landfill gas at a more rapid rate (sooner after waste placement in the landfill). To be at least as protective of human health and the environment as the new source performance standards for municipal solid waste landfills (40 CFR, part 60, subpart WWW-the MSW Landfills NSPS), the site needs to perform the same monitoring required in that rule, at the same frequency and begin that monitoring sooner than the rule requires. The specified monitoring will continue for the duration of the bioreactor project.

A typical gas collection system in a conventional landfill is constructed after the final elevation of the waste has reached. Vertical gas collection wells are installed to collect landfill gas. These wells are typically constructed at about 200 feet radius on center. In the bioreactor landfill the gas collection system will be installed during the waste filling phase of the landfill. The gas collection system will consist of a horizontal 4-inch and 6-inch perforated HDPE pipes and shredded tires. The spacing of the gas collection system in the anaerobic cell will be 100 feet on center and 50 feet on center in the aerobic cell. In the anaerobic cell, after every 30 feet high waste placed a horizontal gas collection pipes will be installed and in the aerobic cell, after every 15 feet of waste. At every gas collection line, a valve will be installed to control and adjust the gas flow rate. The 4-inch gas collection lines in each lift of waste will be connected to an 8-inch lateral line. Each of the lateral lines will be connected to a 12-inch main line which will be connected directly to the main line that is connected to the existing flare and/or engines at the main methane power facility on site. Accurate positive displacement gas meters will be used to measure the volume of landfill gas continuously. Each of the 4-inch gas collection lines will be constructed such that gas pressure, temperature, methane, carbon dioxide, and oxygen could be sampled and measured. The valves at each line will be used to adjust the system for optimum performance. The initial gas collection will be by horizontal wells, operated and tuned, as are conventional wells, for earliest practical gas recovery. This essentially consists of extracting gas at the maximum rate consistent with keeping methane concentration near 50%. Recovery efficiency will be increased and surface emissions limited by a synthetic liner covering as much waste surface as possible during the filling phase, except the working face. After filling phase has been completed the entire surface will be covered with synthetic liner. Gas monitoring will be by gas chromatography and/or a gas analyzer to quantify the methane, nitrogen, carbon dioxide, oxygen, and other gaseous compounds of interest.

Field Monitoring and Control

Moisture content will be monitored throughout the life of the module through the use of a network of moisture sensors to be installed during waste placement. The moisture sensor system used during the bioreactor demonstration project in Module B proved to be very effective and will be the basis for the layout in Module D. At this time, the moisture sensors are planned to be installed at 15-foot increments of depth at a spacing of about 75 feet on center. Using these sensors, the County can determine where liquid application can be increased or decreased to optimize the effectiveness of the system and to prevent build-up of head over the liner.

The quantity of leachate and additional liquids will be measured throughout the life of the module. Once leachate is produced, it will be re-circulated; thereby, reducing the amount of subsequent liquid additions. Liquid will be quantified using flow sensors installed on the leachate discharge line, re-circulation line, and liquid application line. These sensors will provide direct flow readout for determining flow rates in the pipelines and flow totalizing to quantify all of the liquid used and leachate produced.

The head over the liner will also be monitored shortly after the first lift of waste has been placed using a network of pressure transducers and bubbler gages. These devices will be installed on the primary liner, immediately before waste placement, to provide measurements of the leachate depth.

In the event that the transducers indicate that the head is going to exceed the allowable value, the system will automatically start pumps to reduce the liquid level and shut-off valves to reduce the liquid application rate. A computerized control and monitoring system will be used to accomplish this task. This system which originated in the utility and petroleum industries, is often referred to as Supervisory Control And Data Acquisition system (SCADA), such systems are now widely used in many different applications such as waste water treatment systems. These measures would be used to reduce the liquid application rate across the entire module or specifically, in the area of head build-up. Generally, application of the liquid will only be continued until the gas generation phase of the unit it has stabilized, at which time leachate production and recirculation may already have stopped and the leachate should have stabilized some time earlier. The quality of the leachate will also be closely monitored to evaluate the system.

Aerobic Cell Operation and Monitoring

In addition to liquid delivery to the waste, air will be delivered to the aerobic half of the bioreactor disposal area. The aerobic decomposition of the waste and gas generation also requires the moisture condition be maintained slightly above equilibrated field capacity. However, the aerobic process is accomplished at a higher temperature and is somewhat more aggressive in the biodegradation activity. This requires a significant increase in the quantity of water necessary to achieve optimum biodegradation, as compared with the anaerobic process.

The degradation and gas generation of the waste is also related to the temperature within the decomposing waste. The effectiveness of both aerobic and anaerobic bioreactors is dependent on keeping the system within optimum temperatures; therefore, temperature gauges will also be installed to aid in the operation of the system. As with the moisture sensors, temperature gauges were also placed in the waste of the demonstration bioreactor and proved to be very effective. The temperature gauge network will be placed in a similar pattern to the moisture sensors at designated intervals throughout the waste mass.

In the aerobic section, during filling, horizontal gas conduits will be installed in similar manner to those of the anaerobic bioreactor. However conduit spacing will be 50 feet on center horizontally and 15 feet on center vertically. Gas will also be extracted from the base LCRS layer via the conduit collection pipe as filling proceeds. The purpose of this extraction system design is to lower methane emissions that would normally occur to the atmosphere during filling. After filling, chipped tires and pipe conduits will be used to pull or push atmospheric air through the waste under an impermeable cover. It is expected that this will increase the rate of degradation but inhibit methane formation. Large-scale positive gas displacement meters, similar to meters used for the demonstration cells will monitor the gas quantity.

Aerobic and Anaerobic Cell Separation

Separation of the two bioreactor systems will be performed using a composite liner system made of a one-foot of low permeability clay liner and a 40-mil LLDPE liner constructed below the aerobic cell and on top of the first lift of waste in the anaerobic cell. The leachate and gas collection system for the aerobic cell will be isolated from the anaerobic cell.

Daily Cover

Daily cover operations will be performed in a similar fashion to the methods currently employed at the landfill. This includes the use of alternative daily covers such as green waste and tarps. Final cover will consist of a gas piping collection system within a layer of chipped tires in lieu of gravel. The liquid injection system will also be placed within this layer to facilitate delivery of liquid to the waste. This layer will be overlain with a geomembrane cover to control moisture conditions, control gas emissions, and satisfy regulatory requirements to control vectors, fires, odors, blowing litter, and scavenging.

Settlement Monitoring

As areas of the module reach their design grade, monuments will be installed to monitor settlement caused by degradation of the waste. These monuments will be checked bi-monthly at first and less often as the rate of settlement slows. Annual aerial topographic surveys will also be performed to aid in the evaluation of settlement and the effectiveness of the bioreactor system.

Contingency Plan for Failure of the Primary Liner System

The primary liner system is contained by a secondary liner system that provides for an intermediate leak detection system. A sump is located at the low point of this leak detection system and the sump will be monitored for presence of liquid monthly. If any liquid is collected, samples will be tested to determine if there are any leaks in the primary liner system. If the test result from the sampled liquid indicates that there is a leak in the primary liner system then a pump will be installed in the sump to control liquid accumulation in the sump. The liquid level in the primary liner system will be evaluated and monitored to minimize liquid depth above the primary liner. The liner leakage rate and the leachate injection rate will be monitored and reduced if necessary to control the rate of leakage.

Contingency Plan for Landfill Fire

Over 323 temperature sensors will be installed in both the aerobic or anaerobic bioreactor landfill to monitor and record landfill temperature continuously. The Supervisory Control And Data Acquisition (SCADA) system will be used to record any significant temperature fluctuations within the waste that is more than 2 degrees Fahrenheit per day. If such temperature fluctuations are recorded the SCADA system will notify the operator that the system may need to be tested for CO presence. Gas samples will be collected and tested in the field for presence of CO, which will indicate possible internal fire. The location of the possible internal fire in the bioreactor will be determined from the recorded temperature by SCADA system and the location of CO presence. The rate of liquid injection in that area will be increased to reduce waste temperature. In the aerobic bioreactor the SCADA system will automatically turn off the air injection system to control the internal fire. If the liquid injection rate is not sufficient to reduce the temperature or it's not functioning properly, then a liquid injection well will be drilled from above. This well will be used to inject liquid in the area where possible fire is expected. The SCADA system will be used to continue monitoring the waste temperature after this treatment for an increase or decrease in waste temperature.

On top of the primary liner system, for the anaerobic bioreactor, four 600 feet long 3-inch perforated pipes will be installed to deliver cool groundwater in order to reduce the liner temperature and protect the liner from damage. The leachate pump sumps for the anaerobic bioreactor have been designed to handle twice the volume of the anticipated liquid addition, without any significant liquid head build up over the liner. If necessary, for a short periods the pumps could be turned off so that liquid would build head over the liner and protect the primary liner system from excess heat. This method is not preferred over the other methods mentioned earlier. For the aerobic bioreactor, the bottom elevation of the cell is about seven feet from the primary liner system. Before any waste is place in the aerobic cell a low permeability clay liner and a 40-mil LLDPE liner will be constructed to separate the aerobic cell from the anaerobic cell and measure liquid and gas volumes accurately. This will also serve as a firebreak between the two cells.

With all of these operational systems in place, the performance of the bioreactor and effectiveness of the LCRS and gas collection system can be thoroughly monitored. These operational systems far exceed the requirements of Title 27 and Subtitle D; thus, providing another basis for allowance of the Module D bioreactor project.

SUPERIOR ENVIRONMENTAL PERFORMANCE

As discussed further below, a bioreactor landfill is focused on yielding the following superior environmental benefits: a) maximizing landfill gas control and minimizing fugitive methane and VOC emissions; b) landfill life extension and/or reduced landfill use; c) leachate treatment and disposal benefits; d) lessened long-term risk and need for monitoring; e) landfill Gas Energy Project Potential, and f) landfill Mining Potential. These are discussed further below.

a) Maximizing landfill gas control and minimizing fugitive methane and VOC emissions. Landfill gas as generated contains 55% to 60% methane, a potent greenhouse gas. In terms of climate effects methane is second in importance only to carbon dioxide. Landfill gas is a transporter of volatile organic compounds (VOC's) that are air pollutants. Landfill gas capture is maximized by a subsurface permeable gas collection layer overlain by a cover of soil with embedded membrane. Gas is withdrawn to maintain this permeable layer beneath surface containment under a slight vacuum. The capture of methane is further facilitated and eased by a shortened generation interval, from 30 to 50 years to between 5 to10 years through enhanced decomposition. A horizontal gas collection system will be installed as waste is placed and collection of gas will begin as soon as waste begins to generate landfill gas. In addition, the geomembrane cover will improve the overall collection efficiency of the landfill gas system. With this gas capture approach, it is expected that fugitive landfill gas emissions will be reduced for reasons that include:

- Reduction in emissions through installation and operation of gas collection system before the final fill height has reached and before it's required by Clean Air Act NSPS regulations.
- Collection efficiency improvements with the proposed horizontal gas extraction method over vertical gas well efficiency.
- Reduction in long term emissions, from landfill gas generation occurring slowly beyond 30 years post-closure.

The Yolo County's small-scale demonstration project has already shown close to a tenfold increase in methane recovery rate compared to conventional landfills, which suggest a tenfold reduction in interval of methane generation. Available indications as well as basic physical principles suggest that capture effectiveness approaches 100% so long as slight vacuum is maintained within the permeable layer.

A recently completed study by IEM for the Federal Energy Technology Center of the U. S. Department of Energy indicates that wide application of controlled landfilling could reduce US greenhouse gas emissions by 50-100 million tons of CO_2 equivalent when both emission prevention and fossil CO_2 offsets are taken into account. This major reduction in CO_2 equivalent emissions is also cost-effective. In this analysis for FETC (IEM, 1999), over a range of representative landfill conditions, greenhouse gas abatement was estimated as attainable at a cost of \$1 to \$5 per ton of CO_2 equivalent which represents extremely low cost compared to most other options presented in the recent EIA Report (USDOE Energy Information Agency, 1998).

b) Landfill life extension and/or reduced landfill use. The more rapid conversion of greater quantities of solid waste to gas reduces the volume of the waste. Settlement in the Yolo test cell is already over 18% in three years. Volume reduction translates into either landfill life extension and/or less landfill use. Thus bioreactor landfills are able to accept more waste over their working lifetime. Alternatively, fewer landfills are needed to accommodate the same inflows of waste from a given population

c) Leachate treatment and disposal benefits. Bioreactors promise more rapid leachate stabilization in terms of pollutant load, reduced leachate environmental impact, and elimination of need for most discharges to treatment facilities. The bioreactor processes, both anaerobic and aerobic, have been shown in studies at many scales to reduce the content of many leachate pollutants. These include organic acids and other soluble organic pollutants. Since a bioreactor operation brings pH to near-neutral conditions, metals of concern are largely precipitated and sequestered or immobilized in waste. Thus free liquid concentrations and mobility of metals of concern are reduced compared to "conventional" landfill practice where more contaminated lower-pH leachate is often observed to be generated slowly for years. For example, in the Yolo test cell demonstration leachate reached near-neutral (pH 7) conditions within four months after liquid additions and recirculation commenced.

Although not a direct environmental benefit, a need for offsite leachate treatment should be avoidable altogether as long as waste landfilling continues concurrently with bioreactor operation. The additional leachate that would have to be treated at a wastewater treatment facility expansion could be avoided. Because bioreactors almost invariably require extra liquid for optimum performance, and leachate and condensate reintroduction are permissible (40 CFR 258.28), continuing operation of a landfill as a bioreactor allows generated leachate and condensate to be reintroduced so long as new dry waste continues to flow into the landfill. Additionally, calculations indicate that operation of even a small fraction of the landfill aerobically can consume leachate so long as generated, because of the high capacity of the aerobic reactions to evaporate liquid.

d) Lessened long-term risk and need for monitoring. The bioreactor approaches (anaerobic and aerobic) offer potential substantial reductions in post-closure care needs and costs. With present conventional practice, it is highly likely that gas management will be required for at least a mandated 30-year post-closure period. This entails all of the associated expense of continuing monitoring and gas well adjustment. Higher pollutant strength leachate must continue to be managed. A number of other management needs occur as waste continues to decompose, including dealing with subsidence, gas collection line breakage caused by subsidence, and the like.

e) Landfill Gas Energy Project Potential. Yolo County is considering several other alternatives for energy projects such as: (1) self-wheeling of generated power, (2) using increased generation at the landfill for sale to the grid (2 MWe are being generated but the permit would allow up to 12 MWe), (3) local boiler use of gas (4) sale of power to the adjacent City of Davis Wastewater treatment facility, and (5) sale of landfill gas to greenhouse farmer adjacent to the landfill. More predictable gas generation rate and higher collection efficiency will increase the economics of installing such projects and therefore would increase the number of projects that will be developed which would reduce the fugitive emissions from such sites.

f) Landfill Mining Potential. Although landfill mining is not listed in this project, the removal and re-use of waste for beneficial purposes, such as compost for alternative daily cover used on site in other landfill modules is a distinct possibility that County will be investigating in this project. If landfill mining were carried out, it would occur when sufficient stabilization has been achieved. For the anaerobic cell this could be beyond the expected 5-year term of the XL agreement. However, landfill mining or other beneficial use of the waste could also qualify for credit as composting. We have discussed this with the state regulators and agencies and will be conducting a mining pilot project to mine waste from the older section of the landfill. Feasibility of this operation will be determined to estimate the cost for possibly mining the aerobic cell within the 5 year Project XL agreement period. When funds become available the County will explore mining the aerobic bioreactor to quantify the level of biodegradation and the amount decomposed matter that would be reclaimed from the landfill.

ACKNOWLEDGMENT

Yolo County wishes to acknowledge the contribution and efforts of the following individuals and organizations that have made the Yolo County Full-Scale Landfill Bioreactor project possible. The project would have not moved into it's full-scale phase without the financial support of the project from the California Integrated Waste Management Board (CIWMB) and the National Energy Technology Laboratory (NETL). The support of EPA Project XL staff is greatly appreciated for assisting the County to put together the First Full-Scale Landfill Bioreactor EPA Project XL which was submitted in January of 1999.

Don Augenstein of the Institute for Environmental Management (IEM) of Pal Alto, has made major contribution towards the development of the EPA Project XL proposal and has provided valuable technical support for the project since it's conception in 1989.

The assistance and technical support of John Pacey of EMCON/IT Corporation for EPA Project XL has been a great benefit to the project and greatly appreciated.

We also acknowledge the support of the Board of Supervisors and the Staff of Yolo County who's hard work and dedication have resulted in a project that has made Yolo County well know in the field of solid waste for it's contribution to this industry.

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