I. Introduction

Yolo County, proposes to operate its next 12-acre landfill module near Davis, California as a controlled bioreactor landfill to attain a number of environmental and cost savings benefits, which are described below. Co-sponsors of the project with Yolo County are the Solid Waste Association of North America (SWANA) and Institute of Environmental Management (I E M, Inc.). As part of this proposal, Yolo County is requesting that U.S. EPA grant regulatory flexibility from the prohibition in 40 CFR 258.28 Liquid Restrictions, which may preclude addition of useful bulk or non-containerized liquid amendments, and flexibility on other restrictions regarding landfill cover and containment. Liquids including groundwater, and possibly gray water and food-processing wastes normally having no beneficial use, can beneficially enhance the biodegradation of solid waste in a landfill.

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.

Finally, other variations with respect to current regulatory treatments are being requested and the reason for these requests will be discussed below.

A. Description of the Facility/Community/Geographic Area

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. It is located at the intersection of Road 104 and Road 28H, 2 miles northeast of the City of Davis. 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, wood and yard waste recovery and processing area, and concrete recycling area.

Adjacent land uses include a wastewater disposal area (spray irrigation fields) operated by Hunt-Wesson west of the site, and the City of Davis Wastewater Treatment Plant lagoons located immediately east and south of the landfill. The Willow Slough By-pass runs parallel to the southern boundary of the site. The remainder of the land uses adjacent to the site are agricultural (row crops).

There are approximately 28 residences scattered within a 2-mile radius of the landfill. The closest residence is located 1,600 feet south of the landfill and city treatment plant lagoons, on the west side of Road 105 south of the Willow Slough By-pass.

Groundwater levels at the facility fluctuate 8 to 10 feet during the year, rising from the lowest in September to the highest in March. Water level data indicate that the water level table is typically 4 to

10 feet below ground surface during winter and spring months. During summer and fall months, the water table is typically 5 to 15 feet below ground surface. In January 1989, the County of Yolo constructed a soil/bentonite slurry cutoff wall to retard groundwater flow to the landfill site from the north. The cutoff wall was constructed along portions of the northern and western boundaries of the site to a maximum depth of 44 feet and has a total length of 3,680 feet, 2,880 feet along the north side and 800 feet along the west. In the fall of 1990, irrigation practices to the north of the landfill site were altered to minimize the infiltration of water.

Additionally, sixteen groundwater extraction wells were also installed south of the cutoff wall in order to lower the water table south and east of the wall. The purpose was to depress the water table to provide vertical separation between the base of the landfill and groundwater.

Prior to placement of the slurry wall and dewatering system, the groundwater flow direction was generally to the southeast. Under current dewatering conditions, the apparent groundwater flow paths from most locations at the site are towards the extraction wells located along the western portion of the northern site boundary. In essence, a capture zone is created by the cone of depression created by the ground water extraction system, minimizing the possibility of off-site migration of contamination.

Is the project in an attainment or non-attainment area?

The project is in an air district (Yolo-Solano Air Quality Management District, YSAQMD) which is currently non-attainment for ozone. It is expected, as explained below, that the project will reduce emissions of ozone precursors present in fugitive landfill gas emissions, and thus reduce ozone, in the district. Exact ozone precursor values and reductions are not available but significant reductions are expected

B. Contact Information

Ramin Yazdani, Solid Waste Division Manager/Chief County Engineer
Phone (530) 666-8848; Fax (530) 666-8728
Email: ryazdani@dcn.davis.ca.us

Yolo County Planning and Public Works Department
Division of Integrated Waste Management
292 West Beamer Street
Woodland, CA 95695

II. Project Description

A. Summary or overview of project

Sanitary landfilling is the main 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. Although there has been much advancement in sanitary landfilling, there are still problems with "conventional" landfilling practices. Conventional landfilling frequently results in very slow waste decomposition since regulations effectively dictate that landfilled waste be kept as dry as possible. Further, dry landfills pose serious liabilities long into the future as the waste remains undecomposed or decomposes only very slowly. The long-term integrity of the landfill bottom liner and cap system is questionable. Containment may fail before waste is stabilized and decomposition is complete, posing serious long-term risks to groundwater and air quality, as waste may decompose well beyond the required 30 years of post-closure maintenance or after long-term containment failure.

In a Bioreactor Landfill, controlled quantities of liquid are added, and recirculated as appropriate, to accelerate the natural biodegradation of solid waste and liquid waste. This process significantly increases the biodegradation rate of waste and thus decreases the waste stabilization time (5 to 10 years) relative to what would otherwise occur within a conventional landfill (30 years to a century or beyond). As the waste decomposes, landfill gas is also produced. Landfill gas is primarily a mixture of methane, a potent greenhouse gas, carbon dioxide, and VOC's, which are local air pollutants. Methane is also a fuel, and this by-product of landfill decomposition is a substantial energy resource that can be recovered for electricity or other uses. Other benefits of a Bioreactor Landfill include increased landfill settlement and therefore increase in landfill capacity and life, improved opportunities for treatment of leachate (liquid that drains from the waste), reduction of landfill post-closure activities, and abatement of greenhouse gases.

B. Specific project elements

Yolo County proposes to implement its next full-scale 12-acre landfill module with both anaerobic and aerobic bioreactor sections. The majority of the landfill module will be operated anaerobically. The anaerobic process has already been well-studied and performance criteria have already been established at the 9000-ton scale. An aerobic sector will also be constructed, of size large enough to determine performance parameters at size typical of a full-scale landfill. The anaerobic and aerobic operations will be discussed very briefly in turn, with reference to literature containing much more detail.

The full-scale Yolo County anaerobic bioreactor ”controlled” landfill will combine two key elements:

a) Acceleration of waste decomposition and leachate treatment, via liquid amendments and recirculation through a piping network. This is to accomplish rapid completion of waste stabilization and generation of methane to the maximum yield possible.

b) Near-complete capture of nearly all generated methane, via a freely gas-permeable collection layer beneath a very low-permeability cap. Near-complete extraction with this system is already demonstrated in the 9000 ton test cell.

Additional detail on the ongoing Yolo County 9000 ton demonstration project and findings to date include:

(a). Enhanced methane/gas recovery at a rate about tenfold the rate normally seen with conventional landfill practice. Data so far suggest time to anaerobic bioreactor stabilization may be reduced by severalfold, possibly to less than 1/5 that with conventional landfilling

(b) Reduction to close to nil of fugitive landfill methane and VOC emissions with the chosen collection means. Collection is by extraction from the freely gas-permeable surface layer, kept at slight vacuum,. overlying the waste and beneath very low-permeability surface cover. This approach assures recovery of all gas generated beneath the permeable layer, hence nearly all gas generated by waste.

(c) With the same collection approach, reduction in emissions of local air pollutants by at least the same fraction that landfill methane is reduced (95% or more)

(d) Volume loss of ca. 15% in the 2.5 year of enhanced operation so far. This suggests landfill life extension of over 15% possible by taking advantage of the extra air space made available

(e) Bioreactor liquid additions can be slow and very carefully managed while attaining excellent methane enhancement. In the Yolo demonstration, with purposefully slow and careful liquid additions, liquid outflows were constrained to a maximum superficial velocity of 3 cm^3/cm^2.day (about 1.2 in/day) and that only briefly. With the proposed full-scale module drainage layer slope and length, a maximum hydrostatic head can be calculated for this maximum outflow. Assuming conservatively that tire shred drainage packing permeability is equal to 0.5 cm pea gravel, the maximum hydrostatic head over the base liner is calculated at 2.5 cm., or less than 1/10 of the allowed federal and California State statutory maximum.

(f) A further degree of controllability of head is available from the fact that liquid additions can be limited or reduced as needed. Data show control of liquid introduction to rapidly control or reduce outflow within a period of hours to a day or two (clearly evident in Moore et. al. 1997).

(g) No measurable leakage in the primary liner system of the enhanced cell. This is consistent with data from Othman et. al. showing primary composite liner leakage rates of 0-50 liters/hectare day, Most values in Othman et. al. are consistent with negligible/no leakage (below detection limits, less than 2 liters/hectare day.) for monitoring periods within the first few years after base composite clay-geomembrane lining construction

(h) Leachate pollutants stabilizing rapidly, in under a year to concentrations well beneath those typifying the surrounding conventional landfill at the same site. (Comparable conventional landfill leachate pollutants very some, but all are higher)

The aerobic landfill differs from the anaerobic by being, basically, a process of aerobic composting. However the aerobic composting is accomplished within the landfill rather than in windrows or other situations in which composting is normally practiced In this process air is introduced in a controlled fashion into the landfilled waste. Recent representative references on aerobic landfill bioreactor processes include Johnson and Baker, 1999 and Bernreuter and Stessel. 1999. These sources indicate that "in-landfill" aerobic composting is possible. Landfill methane energy is sacrificed, but advantages include the suppression of landfill methane by heat and oxygen. Also, significant waste fractions such as lignin and ligneous materials, which are not degradable anaerobically are degradable aerobically. Thus it should be possible to achieve greater volume reduction by aerobic processing compared to anaerobic. The advantages of aerobic bioreactors are available in principle, but large scale data to show these advantages are as yet sparse. Potential drawbacks such as VOC and other emissions are not well established. Bernreuter notes much further work is needed on aerobic landfill processing, which is one reason for proposing this as part of the Yolo scaleup.

The major difference between bioreactor (both anaerobic and aerobic versions) and conventional landfill operation lies in controlled addition of supplemental liquid. Supplemental liquid required to attain "field capacity" and optimum performance will in most cases be over and above that available from the frequently-discussed "leachate recycle". The factors which are of most relevance to regulators are the risks involved with supplemental liquid additions and the safeguards and controls which can be employed to minimize these risks. A number of safeguards are available and have already been applied in the Yolo Demonstration as discussed above. Project safeguards will also be discussed later under regulatory flexibility section.

III. Project XL Criteria

A. Superior Environmental Performance

1. Tier 1: Is the Project Equivalent?

The existing information from the Yolo County demonstration identifies no significant adverse environmental impacts, that is, worsening of environmental impacts relative to conventional practice. Although leachate may be emitted in quantities at times greater than with conventional practice it can be well-controlled; further, all emitted leachate can be re-used in the process. The other issue to be considered is any extra pollutant increment emitted by greater gas energy use. Here there are two things to consider. One is that advanced power generation approaches such as fuel cells (tested under EPA sponsorship in CA) will limit pollutant emission; the second is that all landfill gas energy use will offset fossil fuel (the most likely "swing" fuel) somewhere else.

This particular XL pilot would produce environmental performance at minimum equivalent to Tier 1, in all areas.

2. Tier 2: Superior Environmental Performance

For convenience the various aspects of superior environmental performance are summarized in table 1 on the next page. Table 1 will be referenced at appropriate points below.

The benefits of present interest to the County are greater energy recovery from anaerobic operation, which will result in more electricity generation, and landfill life extension. Present landfill capacity is sufficient until the year 2020, and the County would like to see its ability to landfill waste extended farther into the future, to 2030 or 2040. The County is also very interested, on its own behalf and others' behalf, in reducing the anticipated postclosure expenses and liabilities that are presently associated with conventional landfilling.

With a Bioreactor Landfill, superior environmental and waste management result include: a) Minimizing fugitive emissions of landfill methane, b) Greater recovery of landfill methane renewable energy, c) Landfill life extension and/or reduced landfill use, d) Leachate-associated benefits, e) More rapid waste stabilization, f) Potential for earlier re-use of landfill land for beneficial end uses, g) Better landfill gas control, and h) Landfilling Mining and Reuse. These are summarized in Table 1 and discussed further below.

a. Minimizing fugitive emissions of landfill methane, a potent greenhouse gas. Landfill gas capture is maximized and emission reduced to minimal levels, by a combination of a subsurface permeable gas collection layer overlain by a soil cover to prevent fugitive emissions. Operation of this permeable layer beneath surface containment is at slight vacuum so the capture of methane is further facilitated and eased by a shortened generation interval, from 50+ years to between 5 to10 years through enhanced decomposition.

The demonstration project has already shown close to a tenfold increase in methane recovery rate (suggesting a roughly tenfold reduction in interval of methane generation). All indications as well as basic physical principles suggest that capture effectiveness approaches 100%.

Greater, more predictable methane recovery for energy can add still more greenhouse benefit by reducing fossil CO_2 otherwise emitted with fossil energy use. A recently completed study for the Federal Energy Technology Center (FETC) of the U. S. Department of Energy indicates that wide

Superior Environmental Performance

		Conventional Landfill (Yolo without XL)	Proposed Bioreactor Project (with XL): Anaerobic bioreactor	Proposed Bioreactor Project (with XL): Aerobic bioreactor
A	Fugitive Emissions of landfill methane and VOC's	20-45% (fugitive gas before and after extraction/ control period; incomplete recovery [70-85%] during extraction)	5-10% (efficient (90-95+%) capture by permeable layers/trenches begins early, continues through entire gas generation period of 5-10 years)	N/A- (little or no methane expected)
B	Methane generation/ recovery	Low rate over very long term (25-70 years) to less than maximum yield	High rate over short period (5 to 10 years) to give maximum yield	N/A- (little or no methane expected)
C	Life extension for 20 year landfill	0 years gained	For a 20-year "conventional" design, ca. 5 years additional life obtained	Over 5 year life extension expected (data sparse)
D	Future Leachate Contamination Risks	Medium to high (organics and metals) over long term	Lower organics and lower metals for shorter term	Lower organics and lower metals for shorter term
E	Waste Stabilization	25 to 70 years	5 - 10 years (from process initiation)	ca. 2-6 yrs (but not enough data yet)
F	Landfill land re-use	longer wait and higher cost	earlier end use at lower cost	earlier end use with lower cost
G	Landfill gas control	install control within 2 years of filling completion	Efficient control; gas control implemented as filling progresses	Efficient control; methane inhibited by nature of process
H	Landfill Mining	Low to moderate potential	Moderate to high potential	Moderate to high potential
I	Landfill Gas Energy Project Potential	Moderate	High; Superior economics of scale with better gas energy predictability	N/A
J	Monitoring	Long 30 years or more postclosure	Shorter period than 30 years expected for LFG, other emissions	Shorter period than 30 years expected

application of controlled landfilling could reduce greenhouse gas emissions by 50-100 million tons of CO_2 equivalent when emission prevention and fossil CO_2 offsets are taken into account. This major reduction is also cost-effective. Greenhouse gas abatement was estimated as attainable at a cost of $1-5/ton CO_2 equivalent for a range of representative landfill cases, which is an extremely low (by more than tenfold) cost compared to most other options presented in the recent EIA Report (USDOE Energy Information Agency. 1998)

b. Greater recovery of landfill methane renewable energy. Energy recovery is maximized by methane generation rates to higher yield (i. e., full biological potential), more efficient collection, and avoidance of the long-term fugitive methane emissions which are lost to energy use in conventional landfill practice. Bioreactor landfilling greatly increases the predictability of gas generation and therefore the reliability as well as recovery of fuel for energy generation, which reduces the uncertainty and improves economics of landfill gas projects.

c. Landfill life extension and/or reduced landfill use. The more rapid conversion of greater quantities of solid waste to gas reduces volume of the waste. Settlement in the Yolo test cell is already approaching 15% in just under three years. Volume reduction translates into either landfill life extension and/or less landfill use. Thus given 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.

d. Leachate-associated benefits: Bioreactors promise both improved quality, reduced environmental impact, and lessened need for discharge 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/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. In the Yolo test cell demonstration leachate reached near-neutral (pH 7) conditions within four months after liquid additions and recirculation commenced.

A need for offsite leachate treatment may be minimized or avoided altogether as long as bioreactor operations continue at a specific site. Because bioreactors almost invariably require extra liquid for optimum performance, and leachate and condensate reintroduction to waste are permissible (under 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.

e. More rapid waste stabilization. This benefit offers potential reduction in postclosure 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 postclosure 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.

f. Potential for earlier re-use of landfill land for beneficial end uses such as parks, golf courses, etc. The value of land for such end uses near urban areas is specially high.

g. Better Landfill Gas Control. Associated with better landfill gas control, emission of VOC's are also reduced which are of concern as local air pollutants. Some of the benefits, such as better greenhouse gas and VOC reduction are "externalities" for which the County receives no monetary gain. Nonetheless these benefits are of high interest as a matter of U.S. national policy.

h. Landfilling Mining and Reuse. Further benefits such as generation of a compost fraction re-usable for landfill cover or locally are also available and discussed in literature.

3. How We Will Measure the Superior Environmental Performance of our Proposal

Superior Environmental Performance will be measured using the baseline (Tier 1, without Project XL) against the actual results of the pilot (Tier 2, proposed pilot). Yolo County will identify their superior environmental goals for the proposed pilot. The Final Project Agreement would contain key measurements to be evaluated and would identify when and how these should be reported for purposes of project evaluation.

B. Flexibility and other benefits

Project results (to date) from smaller-scale demonstration projects are very encouraging and have demonstrated a tenfold increase in landfill gas generation, increased landfill settlement, improved leachate chemistry, and highly cost-effective abatement of greenhouse gases. Economic analysis of the project shows that implementing Bioreactor Landfilling operations can have significant cost savings and environmental benefits for the Yolo County Central Landfill and other similar sites throughout the U.S. and the world.

C. Stakeholder involvement

Stakeholder involvements for this proposal are demonstrated by prior federal, state, and local support of this bioreactor concept. For example, in 1994,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 abatement cost-effectiveness studies have recently been completed with support from the Federal Energy Technology Center ($48,000).

For this XL pilot, Yolo County proposes to initially utilize an existing community advisory committee to locate potential members of the local stakeholder group. The County will convene periodic meetings of the stakeholder group to obtain comment on this proposal, as well as to brief the group on their progress during the duration of the XL agreement.

Yolo County has recognized the following list as potential stakeholders:

Direct Participants-

Environmental Protection Agency
Solid Waste Association of North America (SWANA)--North America (including Canada, Mexico, and Central America)
I E M (Institute for Environmental Management)
Yolo County Environmental Health
Yolo-Solano Air Quality Management District
California State Regional Water Quality Control Board

Commentors-

California Integrated Waste Management Board
California State Water Resources Control Board
California Air Resources Board
SWANA--California Gold Rush Chapter and Southern California Chapter
Yolo County Waste Advisory Committee
Federal Energy Technology Center, U. S. Department of Energy
University of California at Davis
Geosynthetic Research Institute, Drexel University

Members of the General Public-

Yolo County Citizens
Natural Resources Commission
Sacramento County Public Works Department, Solid Waste Management Division
California Energy Commission
Waste Management Inc.

D. Innovation or pollution prevention

Yolo County intends, as part of this pilot, to continue our ongoing pollution prevention efforts. Regardless of whether a particular component is directly regulated as part of an XL agreement, the County will continue our process of reviewing all pollution prevention opportunities and will report on our pollution prevention progress.

E. Transferability

Yolo County believes that with the approval of this proposed Bioreactor Landfilling concept by Federal EPA, and the state, many other public and private landfill owners and operators might be able to implement this type of technology. The technology is expected to yield substantial economic and environmental benefits for-nearly all regions of the U. S., and as noted, worldwide. Results from Yolo County's Bioreactor Landfill pilot project results have already been shared among many other jurisdictions as well as the private sector throughout U.S. and internationally. Results of the project have been published in technical and trade journals and magazines worldwide.

Following an evaluation of this XL Project by EPA, and the first progress report by the County, and assuming the overall success of the Project, the bioreactor landfill technology used in this project could be transferable to a subset of landfills where conditions are favorable for actively managing the decomposition process and where groundwater protection and gas control are ensured.

F. Feasibility

The project sponsor, co-sponsors, and regulatory agencies as designated in the Final Project Agreement, agree to support the project, subject to any review procedures necessary to implement the legal mechanism for this project. Further, each XL Participant has the financial capability, personnel and senior management commitment necessary to implement the elements of this Bioreactor Landfill XL Project.

G. Evaluation, monitoring, and accountability

The XL agreement will contain both legally-enforceable and aspirational requirements and will establish certain limits and goals for Yolo County's performance. The County will ensure compliance with legal requirements and ensure implementation of processes to seek to meet aspirational goals. The project sponsor will establish a record keeping system to ensure compliance, as well as accurate reporting of environmental performance. While the nature and extent of such reporting will be subject to negotiation, Yolo County will make any such reports available publicly and will specifically discuss our performance with the local stakeholder group.

H. Shifting of risk burden

No shifting of the risk burden will occur.

IV. Requested Flexibility

In general, Yolo County proposes to be able to undertake a proposed Bioreactor Landfill pilot that falls within the limitations established in the XL agreement. The County is requesting specific flexibility under the current state and/or federal regulations requirements for the following areas: A) Liquid addition, B) Base liner requirements, C) Cover material requirements, D) Landfill height and closure requirements, and E) Credit for the composting function performed by the Landfill Bioreactor.

A) Liquids Addition:

For Federal regulations, flexibility in 40 CFR 258.28 is requested. This would allow the use of liquid wastes, groundwaters, gray waters, and septic waste that may be benefit the desired waste decomposition in bioreactors. The specific details as to wastes and compositions allowable would be developed as this and other projects proceed.

The same flexibility in liquid addition is requested in California draft regulations under development. The California regulations now allow for only leachate and condensate reintroduction, which will not be adequate to implement bioreactors

Many studies show that liquid supplements over and above leachate and condensate will be required for optimum performance. The amount of liquids needed for enhancement of decomposition is well above the available leachate generated. In fact, results of the Yolo demonstration "dry" control to which no supplemental liquid was added, suggest that leachate generation from a capped cell will be completely halted and decomposition reaches only a fraction of potential. Methane generation was substantially reduced, at well under the yield of the bioreactor. The rest of the waste appears to remain undecomposed, providing firm experimental support as to the reality of the often discussed "dry tomb". Digester effluents and septic waste, which have shown substantial benefit in enhancing waste decomposition (Augenstein et. al. , 1976 and Walsh et. al., 1981) could also be used, but only water was added in the Yolo project.

B) Base liner requirements

An interim bioreactor lining guideline has been issued in State of California draft regulations dated July 1998. The approach would mandate, base lining of double geomembrane within clay for bioreactors.

Regulators will clearly be concerned about risks in adding supplemental liquid to landfills. Risk is considered to arise from potential for head buildup that can be over federal standard (30 cm), and also from the fact that likelihood of pollutant infiltration into underlying strata is increased. In fact, several safeguards are available to address liquid risks. The safeguards are available through (a) slow, well-managed rates of liquid addition, (b) interrupting additions and (c) use of a high permeability drainage layer. Liquid can simply be added slowly enough so that, at outflow at 100% of inflow, the drainage layer provides a large safety factor to accommodate that outflow. Highly permeable leachate drainage layers such as pea gravel or scrap tire chips are already widely used in landfills. In the Yolo project moisture sensors were installed throughout the waste in both cells to monitor the arrival time of moisture at different depths within the waste. These sensors were used to verify the moisture distribution uniformity of the waste and to track the movement of liquid. Because drainage layer capacity is fixed during design and the rate of liquid addition is controlled during operations, the build up of head on the liner can be easily prevented.

Once indications such as liquid outflow, moisture sensors, and gas generated show sufficient liquid added, introduction of liquid can be halted. The encouraging experience at Yolo project is that outflow fell rapidly, on a time scale of days, once inflow was halted. This rapid response shows that a further measure of safety and control is available from reducing inflow as needed. Halting recirculation two years later likewise resulted in complete cessation of outflow, within six months.

Slow liquid addition, in combination with halting inflow once waste was sufficiently wetted (as indicated by sensors) has proven adequate and highly effective at moistening waste as indicated by all 37 moisture sensors embedded in the enhanced demonstration cell. This approach can be considered a version of "titrating" waste with only the minimum liquid necessary to reach bioreactor conditions. Leachate generation and recirculation are at rates easily accommodated by the drainage layer. The rates of liquid addition are similar to precipitation. In contrast to precipitation, the bioreactor liquid additions can be much more carefully and precisely managed.

For aerobic bioreactors, the liquid outflow and base head is also subject to management by much the same strategy as with anaerobic bioreactors. More water needs to be added in total over time for aerobic operation. On the basis of thermal calculations, added water must amount to about 1 pound of water per 1000 Btu generated from waste oxidized by biodegradation. Necessary water can be metered in to keep outflow within drainage layer capacity. An additional consideration is that most of the added water evaporates. The water evaporation performs the function of dissipating the heat resulting when waste is biologically oxidized.

Another issue, a potential risk that has been extensively examined by the Geosynthetic Institute is clogging of leachate drainage system. This basically occurs in two ways: (a) precipitation reactions such as that of calcium acetate reacting to coat surfaces with calcium carbonate, and (b) the deposition of suspended solids.

The risk occurs when solids film deposition is sufficient to block small openings in cloth covering leachate drainage pipes, or when deposited solids fill and block interstices in drainage layers.

The leachate solids deposition potential can be calculated from its chemistry. Leachate composition analyses are recorded for the Yolo Demonstration throughout the interval of liquid addition. The total volume of deposition, from precipitation and sedimentation, is well under 10% of the interstitial volume of the drainage layer (if all of possible solids buildup were to occur there). The other risk is blockage which can occur with deposition in fine pores, as in geotextile in the flow path. A simple solution to avoid pore blockage is to keep interstitial channels large such as chipped tires or pea gravel. Geotextile and like drainage system barriers with small interstices (i.e. sand, dirt) must be avoided.

In summary, bioreactors can be readily operated successfully with controlled liquid additions and drainage layers to allow large safety margins, and outflow limited by limiting liquid inflow to meet regulatory constraints.

With respect to California regulations it is requested on the basis of above data and reasoning that flexibility in bioreactor base lining be allowed. Specifically, for well controlled bioreactors, lining requirements should be equal for conventional and bioreactor landfills. This lining should simply conform to the federal standard under 40 CFR 258.40 (a) (2) deemed adequate to needs of conventional landfills. Thus it should be adequate for well-operated bioreactors as described above.

C) Cover Material Requirements

The current Federal and California regulations require the use of daily covers and intermediate covers to control vector and preclude precipitation infiltration. However for bioreactor, the need is instead for cover that freely allows liquid permeation. Both the safety and efficacy of this cover material have been demonstrated in several years during operation of the main landfill and test cells at Yolo County Central Landfill.

For California, the recommendation is that permeable cover such as greenwaste continue to be allowed under regulations. The requirement for daily cover that precludes precipitation infiltration may pose practical difficulties and should be eliminated where incompatible with bioreactor and other landfill operations. To facilitate landfill gas collection, final cover should be allowed to consist of a freely gas-permeable layer under a soil cap or an alternate cover materials used until landfill is stabilized.

D) Landfill height and closure requirements

Current regulations across the US ordinarily permit waste filling to a particular depth limit ("plan depth"). However regulations do not take into account the very substantial height reduction as waste would decompose in a bioreactor landfill after liquid addition. One way to take advantage of waste volume reduction is to fill to plan depth, then once decomposition is complete, use the added air space for more filling. However this multistep approach involves more cost, effort, and presents difficulties in bioreactor operation and gas collection with the thinner layer of waste added later.

To take maximum advantage of waste volume reduction, it is proposed that for a given plan depth, some "overfill" to greater than plan depth be allowed, to realize net benefit of added landfill capacity. Decomposition of the entirety of the waste could be accomplished at least cost by processing the entire column (depth) and footprint of waste. Highly efficient gas collection can be accomplished via near-surface highly gas permeable (shredded tire) layers even before final capping. The efficiency of such gas collection is a function of the horizontal gas conductivity which can shown for such layers to be several orders of magnitude greater than the vertical. Once biological decomposition and waste stabilization are complete, the waste can be capped with a cap system that is designed for erosion control or compatible with the final use of the site.

E) Credit for the Composting Function Performed by the Landfill Bioreactor

Although variations exist, composting is in general defined as the controlled biological decomposition of organic fractions of waste.

Current laws credit the waste reduced and thus diverted from landfills when it is composted by conventional methods outside of landfills. Principal reasons justifying this crediting are (a) The waste inflow into, and use of landfills is reduced by conventional composting, and (b) a product with some beneficial use (compost) results.

Similar logic suggests that "in-landfill" composting should receive similar credit. The in-landfill composting will achieve much added volume reduction (of 10-40% over and above ordinary settlement depending on circumstances) thereby reducing landfill use. Landfill excavation to reclaim composted waste for cover or other compost functions has been widely reviewed as an adjunct to bioreactor operations in technical papers.

In the case of anaerobic bioreactors, the product benefit is not only compost, if desired, but also another benefit in the form of increased renewable methane energy. This renewable energy is undeniably valuable in, among other things, reducing the greenhouse gas emissions when fossil fuel combustion is displaced. It can also fuels electricity generation near population centers, and support s "distributed" electricity generation, both valuable attributes.

V. Compliance and Enforcement Profile

Yolo County recognizes that all XL Projects must include legally enforceable mechanisms in order to ensure accountability.

The project sponsor further understands that a violation of a condition of the XL Project or a clear pattern of non-conformance on the part of the County may result in termination of the XL Project and the re-institution of the regulations from which flexibility has been granted.

Both California State regulatory agencies and the California Regional regulatory agencies reserve their rights of inspection and enforcement with respect to the bioreactor landfill in accordance with applicable laws.

VI. Schedule Information

This pilot will be developed and implemented over that time period necessary to complete its desired major objectives, beginning from the date that the final legal mechanism becomes effective, unless it is terminated earlier or extended by agreement of all Project Signatories.

REFERENCES AND BIBLIOGRAPHY

1. Augenstein, D., R. Yazdani, K. Dahl and R. Moore. 1998 Yolo County Controlled Landfill Project. Proceedings, California Integrated Waste Management Board Symposium on Landfill Gas Assessment and Management, Ontario, CA. April

2. Augenstein, D., D. L. Wise, R. L. Wentworth and C. L. Cooney 1976 Fuel Gas Recovery from Controlled Landfilling of Municipal Wastes. Resource Recovery and Conservation 2 p 103-117

3. Johnson, W. and J. Baker. 1999 Operational Characteristics and Enhanced Bioreduction of Municipal Waste Landfill Mass by a Controlled Landfill Aerobic Process. Proceedings, 4th Annual Landfill Symposium, Solid Waste Association of North America (SWANA). SWANA, Silver Spring MD.

4. J. C. Bernreuter and Dr. R. I. Stessel. Review of Aerobic Biocell Research and Technology (Draft) Prepared for the Aerobic Process Subcommittee of the Solid Waste Association of North America, Bioreactor Committee, June 27, 1999.

5. Moore, R. K. Dahl and R. Yazdani. 1997 Hydraulic Characteristics of Solid Waste: Findings of the Yolo County Bioreactor Landfill Project. Thirteenth International Conference on Solid Waste Technology and Management. Philadelphia.

6. M. A. Othman and R. Bonaparte and B. A. Gross. 1997 Preliminary Results of Study of Composite Liner Field Performance. Proceedings, GRI-10 Conference on "Field Performance of Geosynthetics and Geosynthetic- Related Systems. R. M. Koerner., G. R. Koerner and Y. G. Hsuan, Eds. GII Publications Philadelphia, PA.

7. Reinhart, D. R. and T. G. Townsend. 1998 Landfill Bioreactor Design and Operation.

8. (USDOE Energy Information Agency. 1998 "Impacts of the Kyoto Protocol on U. S. Energy Markets and Economic Activity," October

9. Walsh, J. W. G. Vogt, W. Held., R. Kinman, and J. Rickabaugh. 1983 Demonstration of Landfill Gas Enhancement Techniques in Landfill Simulators. Proceedings of 7th IGT International Symposium on Energy from Biomass and Wastes. IGT, Chicago

10. Yazdani, R., Moore, R. Dahl. K. and D. Augenstein 1998 Yolo County Controlled Landfill Bioreactor Project. Yolo County Public Works and I E M, Inc. Yolo County Public Works and I E M, Inc. report to the Urban Consortium Energy Foundation (UUCETF) and the Western Regional Biomass Energy Program.

11. Yolo County Public Works and I E M, Inc. 1997 Methane Enhancement by Accelerated Anaerobic Composting at the Yolo County Central Landfill. Initial Test Cell Design, Engineering and Startup. Final Report to the California /Energy Commission, June 1997.