IV. REPAYMENT

REGULATORY IMPACT ON THE COMMERCIALIZATION OF ENHANCED LANDFILL TECHNOLOGY

The California Regional Water Quality Control Board-Central Valley Region (RWQCB-CVR), one of the agencies that regulates the Yolo County Central Landfill, will not allow liquid to be added to a conventional Class III landfill cell. The reason for this is the concern that the addition of liquid would result in increased hydrostatic head on the landfill base liner resulting in increased risk of groundwater contamination. The enhanced cell for this project was required to be constructed with a double liner system, as normally required for liquid waste surface impoundments. The requirement of a double liner increased the cost of the enhanced cell considerably. It is estimated that a double liner system for a full-scale landfill would increase the cost of landfill construction by at least $50,000 per acre (see Projected Economics Section). This requirement could render the application of this technology economically prohibitive.

The view of the Yolo County Division of Integrated Waste Management is that the addition of liquid to the landfilled waste is possible without causing excessive hydrostatic head on the base liner. The goal is not to saturate the waste, but rather, to add liquid in a managed way, until the waste reaches its field capacity (the point at which liquid begins to drain). Managed liquid additions, when used with an efficient leachate removal system, should preclude the buildup of hydrostatic head. A pressure transducer was placed at the lowest point in the leachate collection trench in order to monitor this assumption. Information from this transducer will be used to guide the liquid management program for the project. Data collected in this way will be provided to the RWQCB-CVR for evaluation and recommendations. If the collected data supports the notion that hydrostatic head can be avoided, the RWQCB-CVR would be asked to allow the managed addition of liquid to the landfilled waste placed in conventional waste management units with composite liners.

The acceptance or rejection of a single liner model by the RWQCB could very well determine the future of the enhanced landfill project at YCCL. A double liner requirement would severely impact the economic feasibility of large scale applications, thus, a decision must be made with regard to the increased costs of a double liner system. In any case, if the RWQCB continues to require a double liner system where liquid additions are used, it does not mean the technology could not be applied elsewhere with only a single liner. Site specific conditions at other locations might permit local regulators to allow such an implementation.

It is expected that at least two years of operations and monitoring of the enhanced cell will be required before enough data can be accumulated to develop a presentation to the RWQCB. At that time, if the data warranted it, a revision to our Waste Discharge

Requirements would be requested which would allow liquid addition to the waste in Module C, to be constructed during the summer of 1996. It is assumed that gas generation well beyond that expected from conventional landfilling would be seen within one to two years, with a corresponding increase in revenue to Yolo County. Based on this scenario, repayment could begin within five years, allowing two years to gather data, a year for Waste Discharge Requirement revisions, and another two years for increased revenue from gas production to be realized.

METHANE POWER GENERATION AND THE CALIFORNIA PUC

The cost of full-scale application must be justified by prospective incremental energy revenue to Yolo County. With utility deregulation and other factors, the possible incremental energy revenue is much less certain. The contract existing prior to March 1995 between the Pacific Gas and Electric Company (PG&E) and Yolo Energy Partners, whereby PG&E had agreed to purchase electricity at favorable rates until 1998 (Standard Offer 4) was bought out by PG&E. Termination of the contract occurred without either knowledge or participation of the two other stockholders, EMCON and Yolo County. Yolo County is hopeful that the restructuring of the energy market currently underway by the California Public Utilities Commission will result in favorable prospects for landfill gas utilization.

CURRENT STATUS OF THE YCCL METHANE POWER FACILITY

The generating facility has now been idle for about a year, however, the facility was recently purchased by the Northern State Power company, a subsidiary of Minnesota Power and Light. The plan calls for the Minnesota Methane company to produce and sell power to Southern California Edison using PG&E's transmission lines. A final agreement as to how all this will work is not finalized, however, and it seems likely that the sale of electricity under a new contract will be at a lower rate. Should electricity sales be possible at a sufficiently attractive rate, enhanced landfilling will be implemented in new modules at Yolo County as originally planned.

V. EXPECTED BENEFITS, CONCLUSIONS AND RECOMMENDATIONS

CRITERIA FOR EVALUATING BENEFITS

A variety of criteria may be used in evaluating benefits based on the assumption that enhanced landfilling will be applied to a major fraction of the wastes (50 to 75% depending on example) landfilled in California. Projections are also made for the United States as a whole.

ENERGY POTENTIAL

The CEC's and Yolo County's principal interest in enhanced landfilling is the recovered energy and resulting revenue derived from applying the process to municipal wastes in California. Derivation of the incremental energy potential is detailed below, with assumptions stated:

1. Municipal landfill waste generation in California will be at the national average rate of 3.5 pounds (2.63 pounds dry) per person per day, based on EPA statistics (Kaldjian, 1990) This waste amounts to 17×10^6 tons as-placed or 12.75×10^6 dry tons per year.
2. Methane generation from one dry pound of waste in a dry unenhanced landfill is about 1.0 ft^3 (Augenstein and Pacey, 1990)
3. Recovery efficiency of methane with conventional well systems is about 60 percent so that about 0.6 ft^3/ lb (dry waste) of methane is recovered.
4. Methane generation from one dry pound of waste in an enhanced landfill is about 1.8 ft^3.
5. Recovery efficiency of methane from an enhanced landfill using a surface membrane is about 95 percent so that about 1.71 ft^3/lb dry waste) of methane is recovered.
6. For simplification, transients are ignored, and operation is assumed to be at steady state.
7. Methane recovery estimates for conventional landfills assume that 50% of California waste would enter landfills with gas systems where the recovery rate is 0.6 ft^3/lb, for a recovery of 7.65×10^9 ft^3/year.
8. The minimum landfill size where enhancement is economical is assumed to be that supporting 1 megawatt of electric power production, at a conversion rate of 0.09 kWh/ft^3. At per capita waste generation of 2.63 dry pounds per day this requires the landfill serve about 60,000 people.
9. 75% of California's landfilled waste will enter landfills of a size such that enhancement is economical.

Using assumptions 1-9 above, the recovery of methane without enhancement would be 7.6×10^9 ft^3, as follows:

17×10^6 tons/year × 2000 pounds/ton × 0.75 (dry/wet weight) × 0.6 ft^3 of methane recovered × 0.5 (fraction of landfilled waste subject to recovery) = 7.6×10^9 ft^3

With enhancement, methane gas recovery would be 32.7×10^9 ft^3.

17×10^6 tons/year × 2000 pounds/ton × 0.75 (dry/wet weight) × 1.71 ft^3/lb of methane recovered × 0.75 (fraction of landfilled waste subject to recovery) = 32.7×10^9 ft^3.

This is equivalent to a net gain of 25.7×10^9 ft^3 of natural gas, which is equivalent to more than 4 million barrels of oil a year. A rough projection for the increase in the domestic energy supply for the U. S. as a whole suggests a figure of at least 100,000 barrels of oil per day. These are preliminary estimates and final numbers will not be known, assuming the approach is successful, for several years. However, they are based on reasonable assumptions and field and laboratory experience.

VALUATION OF ENERGY

Several valuations are possible for the energy that might result from accelerated anaerobic composting of municipal wastes in California. The increased gas volume recovered may be roughly estimated at 25×10^9 ft^3 per year. If valued for energy at a cited wellhead price of $2.00 per million Btu, the value would be $75 million. Converted to electricity at a rate of 0.09 kWh/ft^3 and sold (or wheeled) to a combination of grid and retail users at an average of $0.04/kWh, the valuation of electric power would be closer to 100 million dollars per year. Similar calculations suggest energy values could be several hundred million dollars a year for the US as a whole.

The above defines, grossly, energy produced whose value might lie between $50 and 100 million for California. The economic activity promoted by the energy value, alone, should be of at least similar magnitude. For the specific case where extra gas offsets fuel use and thus reduces expenditures for fuel which would otherwise be purchased outside the state, the state's economy is favorably affected. This is economically equivalent to spending the $50 million or so within the state.

ABATEMENT OF GREENHOUSE GAS EMISSIONS

Currently, uncontrolled emissions of United States landfill methane into the atmosphere contribute to atmospheric methane buildup. Evaluation of the impact of landfill methane on this atmospheric buildup, and its adverse climate change consequences, has been conducted by one of the project participants (Augenstein, D., 1992, and Blake, D., 1994). In summary, U. S. landfill methane emissions are of high significance in contribution to climate change, and in fact may constitute about 1-2% of the totality of the climate change problem.

The assumptions used above for energy calculations for California can also be applied in estimating methane emission abatement. Calculations suggest that applying enhancement to the degree assumed, with the same assumed capture efficiencies, would result in a yearly reduction of methane emissions of about 20×10^9 ft^3 for California (about 40 to 50 percent). Initial studies suggest that enhanced landfilling could also cut total emissions by half, nationwide. This would result in a reduction of about 1% in the annual global warming potential due to buildup of greenhouse gases in the earth's atmosphere. Such a degree of abatement is regarded by those in the atmospheric sciences as a major benefit (Cicerone, R., personal comm., Blake and Augenstein, 1994.)

"Climate change equivalence" of methane to carbon dioxide on a molecular basis can vary, depending on timespan, nature of emission over time, and other factors. One widely applied equivalence ratio of methane to carbon dioxide is that adopted by the Intergovernmental Panel on Climate Change (IPCC). The IPCC assumes equal quantities of methane and carbon dioxide are generated, then integrates the greenhouse effects of both over a 100 year period. Using this approach, the IPCC evaluates methane climate change potency as eight-fold that of carbon dioxide on a per-molecule basis. The abatement of 20×10^9 ft^3 of emitted methane per year in California would equate, by the IPCC standard, to mitigation of about 2.5 million tons of carbon emission (as CO_2). In greenhouse terms, this would equate to a reduction in consumption of 18 million barrels of oil annually for California and about 150 million barrels a year for the U. S. as a whole.

One economic criterion for evaluating greenhouse gas abatement is the expense to mitigate emission of one ton of carbon as CO_2, or the "greenhouse equivalent" of another gas. Costs for CO_2 carbon mitigation range from zero (for some economically self-supporting steps such as conservation) to well over 100 dollars per ton, with higher costs being more typical. US electric utilities participating in the EPA Climate Challenge Program are typically considering steps that cost $10-20 per ton of carbon abated.

It must be pointed out that cost of methane mitigation by enhanced landfilling might vary depending on a number of factors, however, a range of $0.50 to $2.00 per million Btu's to mitigate landfill methane emission seems to be a reasonable assumption. This is equivalent to an abatement cost of approximately $3.00 - $15.00 per ton of CO_2 carbon, which is rather low. Thus, enhanced landfilling appears to be an attractive route to mitigation of emissions of greenhouse gases. Alternatively, the mitigation of 20 billion cubic feet/year of methane emissions to the atmosphere is equivalent by the accepted IPCC standards to the mitigation of 2.5 million tons of CO_2 carbon/year. At $15/ton mitigated, this would have a value of $37.5 million annually.

WASTE VOLUME REDUCTION AND LANDFILL LIFE EXTENSION

Enhanced and conventional landfills experience volume reduction, a key factor in extending the useful life of the facility. Over time, the waste is slowly converted to gas and leachate, with a resulting decrease in volume. In the case of conventional landfills,

this volume reduction occurs slowly over time and is of limited value to the landfill operator. In addition, as the waste slowly subsides, the convex cover layer sags, sometimes forming collection ponds for rainwater, and a potential threat to groundwater due to the accumulation of high-strength leachate within the fill. To cope with this, the operator must periodically move additional cover material over the fill, to maintain convexity in order to shed rainwater. In the case of enhanced landfills, volume reduction can be accelerated to the point that stabilization may occur within a decade of placement. The ability to recover this volume for further filling is certainly beneficial, especially if it can be accomplished within a short, predictable time period. On the other hand, if a landfill operator has gone to the expense of installing an impermeable final cover system, it may be impractical to remove that cover at a later date in order to add more waste. If, however, this objective were planned for early, it might be possible to use a "temporary" final cover during the time of landfill decomposition so that it would not be economically prohibitive to place more waste at a later date.

For the unenhanced case, generation of 2 ft^3 of landfill gas (1 ft^3 of methane with 1 ft^3 of associated CO_2) from one dry pound of waste represents the conversion of 15.8% of the waste dry weight to gas. The enhanced generation of 3.6 ft^3 of landfill gas per dry pound (1.8 ft^3 of methane) would represent conversion of 28.5 % of the waste to gas. Volume reduction proportional to the loss of dry waste seems a realistic assumption. Assuming that such waste volume losses will occur, waste ultimately reposing in the landfill will be changed from 84.2% of the incoming waste, without enhancement, to 71.5%, with enhancement.

This estimated volume reduction is significant because it suggests landfill life can be extended by 10 to 15%, assuming a cost-effective means can be found to add waste after closure. As with energy, several methods could be used to valuate landfill life extension. One way in which savings might occur is that five landfills might suffice for a given inflow of waste if enhanced landfilling were applied, whereas six might be needed otherwise. The savings would include the costs of siting, permitting, land, lining, filling operations and maintenance. One prediction is that by the year 2000 half of the collected gate fees will be used to maintain the waste ultimately remaining in the landfill. This volume reduction is assumed to apply to 75% of the waste produced in California, for an additional waste capacity of 12.75 million tons per year. This leads to an estimated savings of about $30 million annually.

REDUCTIONS OF OTHER POLLUTANT EMISSIONS

Landfill gas contains significant quantities of air pollutants such as volatile organic compounds (VOC's) or non-methane organic compounds (NMOC's). The California Air Resources Board, US EPA and others variously estimate their emissions to be somewhere between 0.1 and 1.0 pounds per cubic foot of methane generated. Assuming that this ratio of NMOC's to total methane is unaffected by enhancement, the abatement of NMOC emissions to the atmosphere associated with a reduction of 20 billion cubic feet of methane emissions per year would be between 2000 and 20,000 tons/year. A nominal value for cost of abatement of emissions from other sources is about $2.50/lb. This

would place a value for this degree of NMOC abatement at somewhere between $ million per year for California alone.

REDUCED POST-CLOSURE LANDFILL MAINTENANCE

The effort now required for post-closure landfill maintenance under Title 14 of the CCR, is considerable. This effort is necessary to maintain containment and particularly gas systems. Typical vertical well gas systems require continuing well-by-well adjustments of gas extraction so that gas is captured with reasonable efficiency while air entrainment is avoided.

Flow maintenance of current, well-based extraction systems is labor-intensive, and may periodically involve drilling new wells, maintaining pipes and blowers, and so on. The result is that gas system costs alone can be estimated at between $0.01 and 0.10 per ton of in-place waste, while gas recovery continues. All of the costs associated with the gas system monitoring and maintenance would be expected to cease if gas production were to end (i.e., reach 95+ % completion) earlier than the mandated 30 years. By reducing the maintenance period of a gas recovery system from 30 years to 10, assuming this reduction applied to the amount of California waste which is landfilled, a savings of $0.04 per ton per year, or $10 million dollars annually, should be realized.

EMPLOYMENT IN CALIFORNIA

Above estimates suggest benefits on the order of several hundred million dollars per year if enhanced landfilling is applied to half of California's solid waste. Employment effects are difficult to predict at this stage.

STEPS NEEDED TO MOVE ENHANCED LANDFILL TECHNOLOGY INTO THE MARKETPLACE

This enhanced landfill demonstration project is being conducted with the intention of eventual full-scale application, as described in the original project proposal to the California Energy Commission.

Application at a full-scale landfill is the logical next step toward bringing the technology to commercial feasibility. However, within California, two factors now impede progress in that direction:

- Deregulation of the electric utility industry has reduced prospective sales revenue from electricity.
- The California regulatory approval process to allow enhanced landfilling appears to require considerable effort, possibly due to the newness of the approach. Regulatory issues at the federal level appear to be resolved at this time.[2]

[2] Personal communications: Andrew Teplitzsky, Chief, Residuals Management (i.e. landfilling), U. S. EPA and Simon Friedrich, Head, Municipal Solid Waste Energy Research and Development, U. S. Department of Energy. Communications with Don Augenstein in 1993, 1994 and 1995.

For these reasons, larger scale applications may need to be considered in other states or countries where circumstances are more favorable. Desirable characteristics of a location for full-scale application include:

- The selling price of electricity should be as favorable as possible (preferably $0.05 per kWh or more within the United States), either due to prevailing rates (avoided costs under PURPA) or because of a given electric utility's commitment to renewable power, as in states such as Minnesota and Wisconsin and in the service territories of New England Power.
- Local regulatory authorities should be willing to permit enhanced landfilling without imposing unduly stringent and time-consuming demands. This should be the case where regulatory authorities are familiar with the technology, its environmental benefits and potential. States that are likely to be receptive are Florida and Delaware, because of landfill test work that has been undertaken in those locations, and North Carolina and Ohio, because of EPA offices in those states which endorse and support bioreactor landfill work.
- There should be willingness of state agencies to provide at least some degree of supplemental funding for the first full-scale application.

Enhanced landfill technology can also be moved forward by organizations which are involved in its implementation. The Institute for Environmental Management (IEM), a consultant to Yolo County on this project, wishes to help other parties undertake enhanced landfilling. IEM has conducted discussions with major landfill engineering firms so that enhanced landfilling services could be provided by IEM and the partner firm. As the technology is successfully demonstrated at one or more landfills, a marketing effort could promote the technology's implementation at other landfills that are likely candidates for successful application.

The time necessary to lay the groundwork for a full-scale project can be roughly estimated at 1-2 years (permitting accounting for a large portion) once the decision is made to initiate a full-scale project. Startup would require another year or more, with perhaps five years needed to determine complete performance characteristics at full scale. Yolo County expects to implement this technology in future landfill modules if the test cells are successful operationally and economically. Other steps that will be taken by the county toward moving this technology to market shall include the following:

- Preliminary data will be distributed in reports and published in technical journals.
- Reports will be provided to other public agencies in areas where this technology could be implemented, such as Sacramento County, Solano County, and Sonoma counties.
- Data and reports will be made available to interested parties such as: universities (UC Davis, University of Central Florida, etc.); local and state agencies (California Integrated Waste Management Board, California Regional Water Quality Control Board, and California State Water Resource Control Board); federal agencies (EPA's Risk Reduction and Engineering Laboratory); for further dissemination.

- Based on recent proposed contract with Western Regional Biomass Energy Program and Urban Consortium Energy Task Force the monitoring data will be made available for further dissemination to the public sector.

OVERALL CONCLUSIONS

This report has described the planning, engineering, construction and startup of two test cells at the Yolo County Central Landfill. The purpose of this project is to demonstrate "enhanced landfilling". Major benefits of this technique are expected to include maximum methane yield, higher generation rate, signifcantly shorter decomposition.

Construction of the test cells has been successfully completed as noted above, and initial data is being collected. A comprehensive measurement program shall run over the next several years, until the methane generation and waste stabilization are near complete. Other benefits might include landfill life extension (or reduced use), reduction of costs for landfill management, and mitigation of environmental impacts from leachate.

It is hoped that successful execution of this demonstration project will lead to much wider application of the technology at sites in the US and worldwide. It is strongly recommended that further development and application of enhanced landfilling be pursued.

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