YOLO COUNTY CONTROLLED LANDFILL PROJECT

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1. ABSTRACT

A new waste landfill bioreactor approach ("controlled landfilling") is expected to provide improved greenhouse emission and waste management benefits over current practice. It is being tested by Yolo County Public Works and its project team, at the Yolo County Landfill, Davis, California USA. Objectives include earlier and greater methane energy recovery, reduced greenhouse methane emissions, other climate benefits, and reduced future environmental risk. Methane recovery and waste stabilization are accelerated through carefully managed additions of supplemental water and leachate. A control cell is operated in parallel. Methane capture is maximized and emissions minimized, by surface membrane, over surface permeable layer operated at slight vacuum to conduct gas to collection. Cells are highly instrumented to determine performance. Rationale and details of this project, and first four years' results, are summarized.

2. INTRODUCTION

The Yolo County, California, Department of Public Works is conducting demonstration-scale testing of an advanced landfill management strategy ("controlled landfilling") at its Central Landfill outside Davis, California USA. Support has come from several sources including the California Energy Commission, Yolo County, and the US Department of Energy's National Energy Technology Laboratory (NETL). This paper provides a project overview and presents encouraging results that have been obtained to date. Readers desiring more detail should consult Augenstein et. al, 1997, 1998.

With "conventional" sanitary landfilling (current US regulations), landfilled waste generally remains relatively dry, for many years after placement. It is now clear that such dry waste conditions retard and limit waste decomposition to landfill gas. This is inferred not only from well-documented long terms of slow landfill gas recovery (SWANA 19-landfill study Vogt and

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Augenstein, 1997) but also by finding un-decomposed legible reading material many decades old, often recoverable from landfill samples (as noted in popular articles by Professor William Rathje). Slow decomposition entails long-term expenses,: dealing with gas system and containment maintenance, problems with continuing subsidence, other landfill aftercare, and leachate pollutants. Importantly, even with all present and expected US regulations, conventional landfilling results in gas recovery to less than potential, inefficient energy use, and often, substantial fugitive methane emissions.

In summary, because of inefficiencies, and fugitive emissions prior to collection system installation and after collection stops, as little as half of generated methane may be collected by conventional systems. Augenstein and Pacey (1991) estimated fugitive fractions may be 10 to 60% depending on site (i.e. collection system efficiencies between 40% and 90%). California's Air Resources Board, in its Suggested Control Measures (1990) estimated escape at 40 to 60% of gas collected, i.e. fugitive gas 30-40%. Walsh (1994) estimated fugitive gas at 25% to 75%. These estimates are for times when controls are operating: Furthermore, much US waste may under current regulations escape gas control either over significant intervals, or completely.

In terms of landfill design, surface membrane ("geomembrane") coverage can enable capture of generated landfill gas with close to 100% efficiency. However such membrane use also results in one serious problem. Membranes prevent moisture (precipitation) infiltration, maintaining waste at low moistures, typically 15-25%. This further slows or even halts decomposition beneath impermeable membranes (Kraemer, 1993, Leszkiewicz, 1995, present work) so decomposition may continue to much longer terms, to a century or to ultimate containment breakdown. Dry containment approaches have been termed "dry tomb" technologies (Lee, 1990). Among "dry tomb" problems are (1) Poor economics for low-rate gas recovery (overall, as well as low rates per unit area) from landfills for extremely long periods due to high fixed annual costs experienced per unit of gas collected. (2) Poorer economics of scale for energy use or flaring of gas recovered at lower rates. (3) Inherent future risks if (or, when) containment ultimately breaks down.

To avoid such problems with "entombing" membrane-covered waste it is highly desirable to accelerate the decomposition to complete within much shorter time spans i.e. operate landfills as bioreactors. Our approach, below, has been termed "controlled landfilling"

3. BIOREACTOR "CONTROLLED" LANDFILLING: APPROACH/ RESULTS

Waste decomposition and methane generation can be promoted by means including control of moisture, temperature, pH, and nutrients. Elevated moisture (by conventional landfill standards) is essential for accelerating methanogenesis (Halvadakis, et. al. 1983). Temperature elevation can also provide major benefit. (an E_a. ca. 15 kcal/mol. implies rate constant doubling for each ≈10C increase over a span from 10°C to 50^{+} C [Ashare, et. al., Dynatech R/D 1977], also see Hartz and Ham, 1982). For US use, a process must (a) be compatible with current US landfill regulations, (b) integrate easily with current practice and (c) pass regulatory scrutiny. With this in mind, water and temperature were the sole enhancement techniques applied, although several other enhancement techniques would be possible as well.

In combination with methane enhancement, a surface gas-permeable ($\geq 10^6$ Darcys) layer, can operate at slight, uniform vacuum beneath surface membrane and provide a good alternative to wells to accomplish near-total gas recovery. Thus, in summary, surface membrane containment with methane enhancement by landfill moisture and temperature can speed completion of methane generation, minimizing fugitive methane emissions (particularly long term) as well as maximizing energy potential.

Anticipated benefits of the approach are in energy, environmental and landfill operation and include (1) Substantially reduced atmospheric emissions of methane, a very potent climate active gas, from landfills. . (2) Near-elimination of emitted organic air pollutants. (3). Completing decomposition and stabilization much sooner, reducing long-term risks to the environment and reducing long-term gas and other aftercare costs. (4) Reduced costs for post-closure landfill care and gas system operation and maintenance due to earlier completion of landfill gas generation and waste stabilization. (5) Maximizing rate and yield of methane recovery (6) More predictable methane recovery, so that landfill-gas-fueled energy equipment may be appropriately sized to fully use gas (7) Better scale economics for energy use of greater amounts of resultant captured gas.

Demonstration cells The project operates two test cells, containing about 9000 US tons waste each. Cells are large (32 meters x 32M x 13M deep) to replicate compaction and heat transfer of landfilling at "typical" waste depths Liquid (wellwater or, later, leachate) was added to the "enhanced' cell via 14 ca. 1 M^3 scrap-tire-filled "pits". Additions were kept below 50 liters/M^2.day with the goal of achieving compliance to US regulatory limits on base hydrostatic head (<30 cm.). A leachate collection and removal system (LCRS) delivered leachate to an external reservoir from which the leachate could be either recirculated to the cell or (ultimately) disposed. The cell "control" differed in receiving no added liquid. Waste in cells was intensively instrumented to establish performance. Moisture/ temperature sensors embedded in the waste during placement totaled 56 moisture sensors and 24 temperature sensors, distributed over three layers in the control cell and four in the enhanced. The cells are shown in oblique schematic in Figure 1 Also monitored are waste volume, leachate flow, composition, static head on the base liner, gas flow and composition, containment integrity, with other key parameters. Sidewalls of compacted clay, used successfully in an earlier demonstration (Pacey et. al. 1987) isolate demonstration cells' waste from the surrounding. Both cells were covered with highly gas-permeable (> 10^6 Darcys) shred tires. The permeable tire shred gas collection layer is overlain with gas-impermeable geosynthetic membrane. Cell filling was largely by "standard" landfilling approaches. However greenwaste (an alternative daily cover) left waste permeable to later moisture additions/ infiltration. This porous cover also allowed limited initial composting, beneficially elevating startup temperature. Waste was typical residential/commercial from packer trucks serving households, small businesses, markets, etc. Tonnages were carefully logged. Loads that were inert were, however diverted. Much more detail can be found in Augenstein et. al., 1997 and 1998

Overall performance objectives at the outset included (a) completing methane generation and biological waste stabilization in under 10 years and (b) demonstrating technique allowing > 90% fractional gas recovery, that is, fugitive emissions well under 10%.

For collection, gas is withdrawn through perforated pipe to a main collection line to maintain slight vacuum, < 1 cm. water head (The vacuum is uniform over the surface permeable layer, thus preventing outward landfill gas leaks). Control and enhanced gas flow are both measured by highly accurate Dresser Industries corrosion resistant positive displacement meters (2 in parallel. A third in series confirms the sum of the first two). Gas composition and particularly the methane of interest is followed by gas chromatography.

Waste was brought to field capacity, by liquid (well water) addition to 14 surface pits, and resulting outflow (leachate) recirculated to attain acceptably high readings of emplaced moisture sensors. Makeup well water was used to overcome any moisture deficit, indicated by either "dry" sensors or minimal or absent outflow. Water was initially added at fairly low rates, estimated sufficient to bring waste to field capacity in 4 months.

The most important results can be summarized:

Refuse temperature: Both cells experienced substantially elevated temperatures, 45-55^{0}C in the bulk of the waste upon filling, attributed to limited aerobic composting occurring after waste placement. The combination of heat inputs from methanogenesis and losses has resulted in desirably high temperatures, now slightly over 40C in the enhanced cell (Figure 2). The control cell with less biological activity (not shown) has now cooled to a mean near 30^{0}C

Moisture flows Figure 3 shows moisture inflows and outflows to the enhanced cell. An important note is that the maximum outflow has been less than 10% of the maximum that could be accommodated by an appropriate drainage layer (say 0.5 cm pea gravel). Inflows and outflows also indicate "as-compacted" waste permeability of (at minimum) 5 x 10^{-5} cm/sec

Moisture distribution Regarding moistures attained, Figure 4 shows, encouragingly, over 90 % of the enhanced cell waste wetted within 6 months after start of liquid addition as indicated by sensors. This basically indicates the infiltration approach to be successful. For the control cell, waste moisture readings remained dry as expected with the exception of the very bottom layer (where moisture has been detected by other means as well, however control leachate generation ceased quickly). Recent test borings (data omitted) support sensor moisture results for both cells and showed encouraging moisture distribution through waste samples from the enhanced cell.

Gas recoveries Cumulated gas recoveries to date are shown in figure 5. Gas recovery has been at substantially accelerated rates. Normalized recovery rate from the enhanced cell to date is compatible with first-order rate constant k ≡ 0.4-0.7 year^{-1}, about tenfold "normal". Peak and averaged enhanced cell recovery rates are to this point the highest, to authors' knowledge, from any waste mass this large anywhere, worldwide. “Normal” gas recovery that would be expected from this waste mass is also shown for comparison in figure 5. The "normal" is based on a major study of recoveries from 19 landfills (Vogt and Augenstein, 1997) as well as widely applied commercial models such as those of EMCON/IT' and SCS Engineers. Results suggest completion of landfill gas generation and stabilization may be possible within the target 10 years or less. It is considered that initially high enhanced cell methane recovery results from both beneficial moisture and temperature effects The control cell exhibited very high early methane recovery as well, over half that of the enhanced. Control cell productivity is speculated as due to temperature effects, which by themselves, given Ea ca. 15 kcal would result in severalfold enhancement with temperatures > 20C over normal ambient. It is also extremely interesting that the "dry" control cell productivity, after this initial burst, has "flatlined' i. e. fallen to near zero. This control cell finding is confirming the famous (or infamous?) "dry tomb".

The conversion of waste to gas is also providing volume reduction, illustrated in Figure 6.

Methane/climate benefits Incremental energy and greenhouse gas abatement potential from wide application of controlled landfilling to US landfills was estimated based on results to date, (IEM, Inc, for National Energy Technology Laboratory, 1999.). . It was assumed that controlled landfilling could be applied to about 70% of US waste. If resultant gas fueled electricity, added time-averaged electrical energy could amount to ca. 4000 MWe over and above that with “conventional” landfill gas collection. This increment of electrical energy is enough to meet total needs associated with all activities of close to 3 million US citizens. Climate or “greenhouse” benefit from controlled landfilling comes via 3 paths: (1) Sequestration of refractory (non-decomposing) photosynthetically derived carbon such as wood, etc.. in the landfill (Note such sequestration is true of all landfills. However climate benefit occurs relative to aerobic composting, or so long as landfills are operated so waste oxidization is prevented--with proper operation, sequestration may last for centuries or millenia.) (2) In the "ideal", offset by landfill gas energy of the fossil CO2 that would otherwise be emitted. (3) Reduction of fugitive emissions associated with vertical well collection and also long-term methane emissions after collection ceases.

The benefits from "controlled landfilling" from these are quite substantial. This is because amounts of organic photosynthetically fixed waste entering landfills and similar waste disposal sites are clearly huge (whatever the imprecisions in statistics). For example,

- the sum of benefits from factors (1) + (2) gives benefit equating to long-term sequestration of 70-90% of photosynthetically fixed carbon in paper, food, pant material, etc. entering given "controlled landfills" (figure 7). For the US, even allowing for uncertainties and variables inherent in calculations, possible US CO_2- equivalent reductions from factors (1) and (2) alone should range from 50-100 million (or more) tonnes CO2eq per year.

- Factor (3) above, prevention of greenhouse methane emissions, provides even greater greenhouse benefit (figure 8).

Thus, summing factors (1), (2) and (3) and considering enormous amounts of wastes managed worldwide,

- added world potential for abatement of CO_2eq by controlled landfills and variants may be 3-5% or more of the total annual atmospheric rise in radiative forcing due to buildup of all greenhouse gases (detailed support available from authors). In any case there exists major climate benefit potential by extant standards.

- The greenhouse gas abatement appears very attractively economical by extant standards (fig. 9)

The Yolo controlled landfill demonstration is meeting intended objectives. Industry and regulatory interest, and environmental potential are high. The next hoped-for step by Yolo County and the project tem is scaleup

In sum, proper management of solid waste landfills worldwide through "controlled landfilling" and variants could greatly help in meeting world greenhouse gas abatement and US domestic energy targets.

ACKNOWLEDGMENTS

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Figure 1. Isometric View of the Enhanced and Control Cells

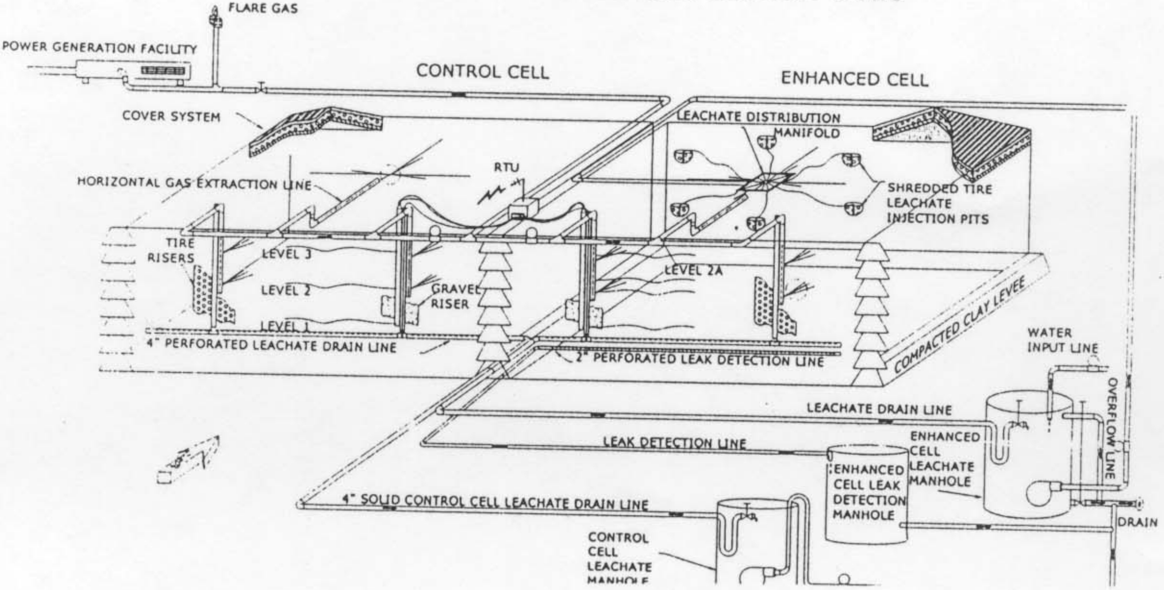


Figure 2. Enhanced Cell Refuse Temperature

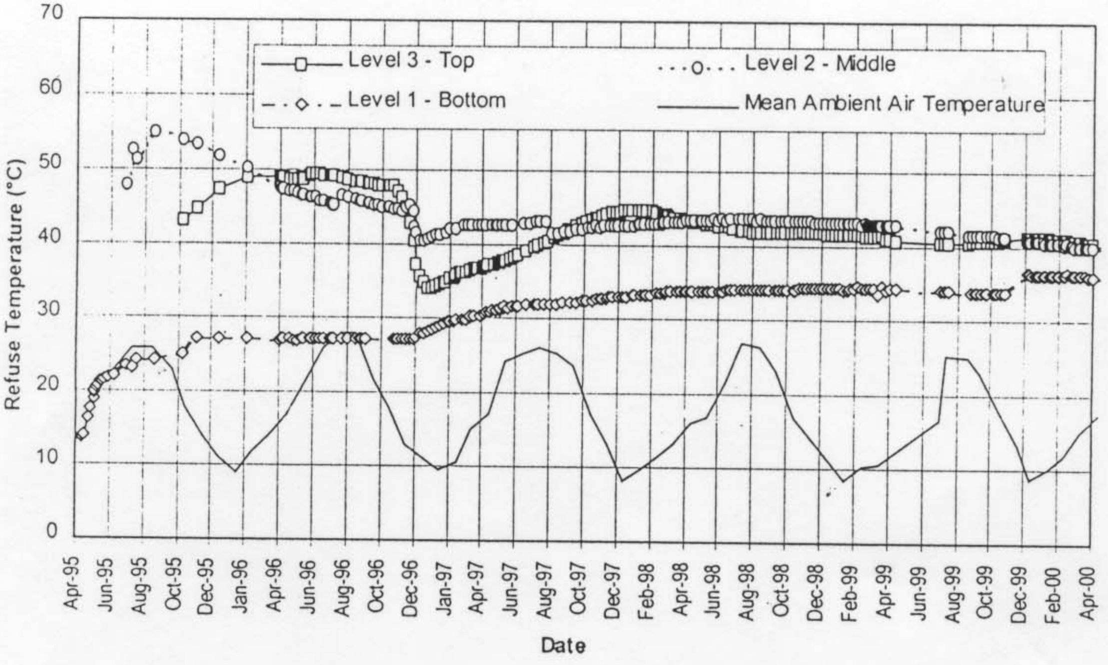


Figure 3. Enhanced Cell Cumulative Liquid Input

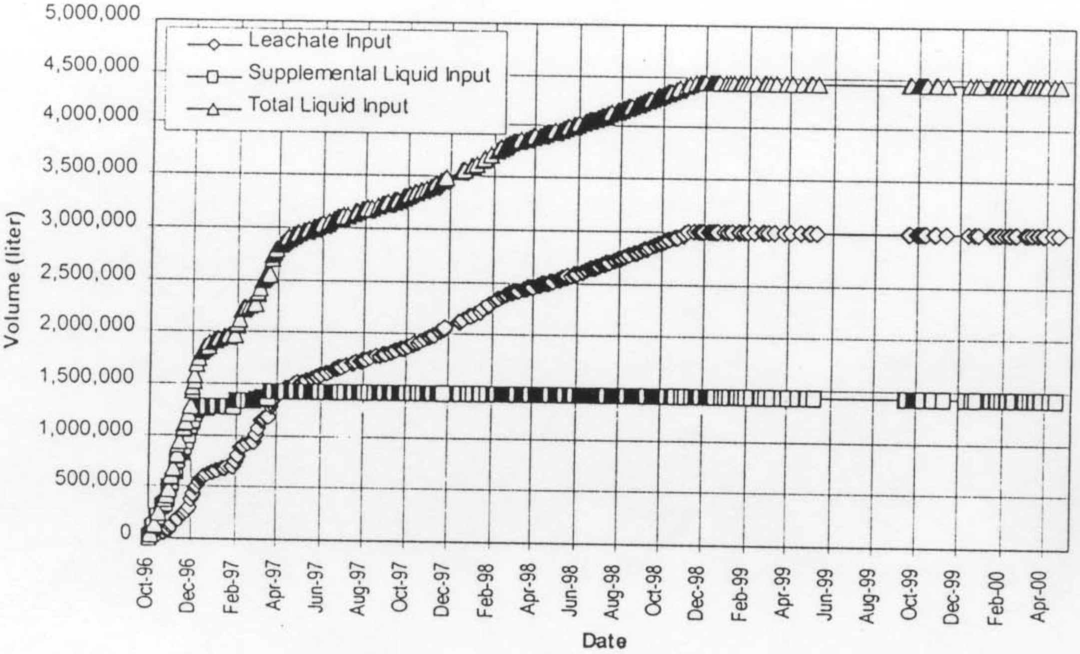


Figure 4. Enhanced Cell Gypsum Block Moisture Readings

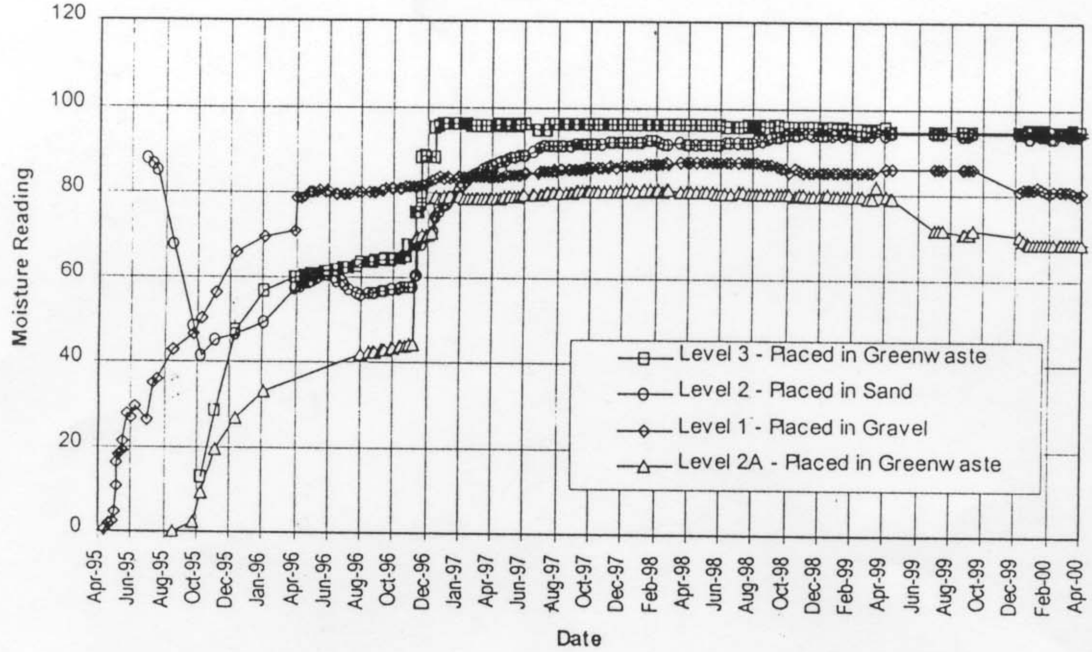


Figure 5. Enhanced and Control Cell Cumulative Methane Volumes

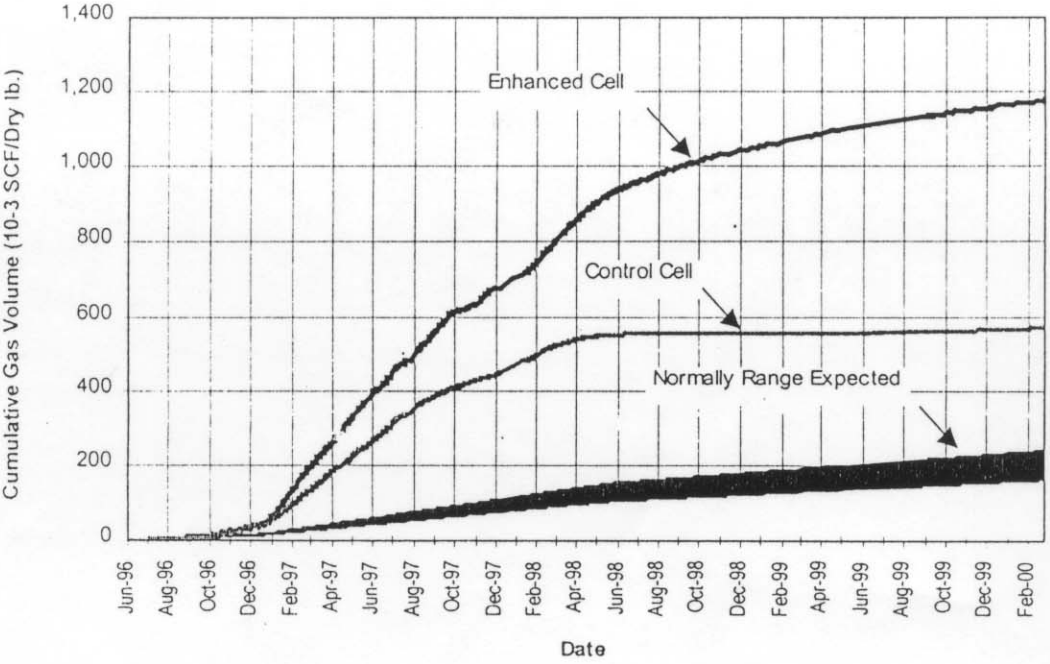
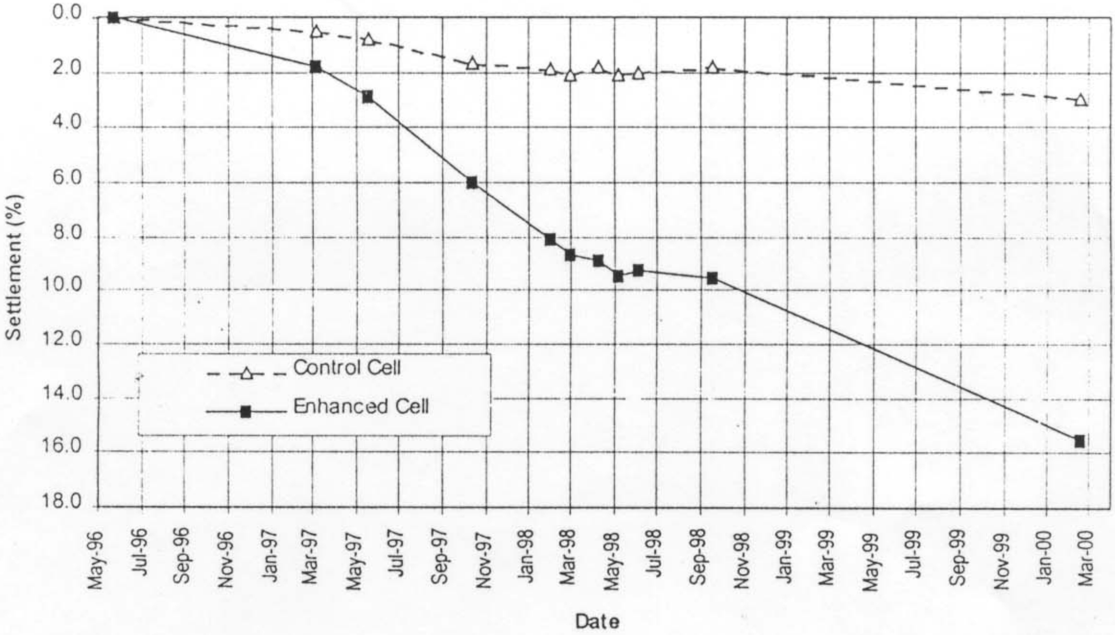


Figure 6. Enhanced and Control Cell Average Settlement



GHG ABATEMENT

CARBON SEQUESTRATION, FOSSIL CO_2 MITIGATION--- "IDEAL CASE" ANAEROBIC BIOREACTOR

Fates, ("balance sheet") for
photosynthetically fixed carbon emplaced in landfill

(A) Refractory (wood, newsprint, other lignocellulose). Stays sequestered in landfill,

all carbon of (A) represents fossil C reduction in atmosphere

(B) Carbon to 55%CH_4/45%CO_2 (= Landfill gas) proximate composition $CH_{2.2}O_{0.9}$ Generated at 90-95% thermal efficiency. Captured at ca. 95% efficiency; used to displace fossil energy.

For (B), fossil C atmospheric emissions avoided

≈ 0.5 carbon/carbon for natural gas
≈ 0.7 carbon/carbon for oil
≈ 0.9 for coal
Ave. about 0.7

- **With energy use, bioreactor LFG avoids from 0.6-0.8 atmospheric fossil CO2 carbon per LFG carbon generated**

CONCLUSION

Total benefits via routes (a) + (b):

CLIMATE EFFECTIVENESS FOR ANAEROBIC BIOREACTOR WITH PRODUCT GAS ENERGY USE CAN EQUATE TO SEQUESTRATION OF 70-90% OF ALL PHOTOSYNTHETICALLY FIXED CARBON ENTERING THAT BIOREACTOR LANDFILL. SEQUESTRATION LONG-TERM, SO LONG AS WASTE DOES NOT OXIDIZE (CENTURIES OR MILLENNIA --PROPER DESIGN CAN ASSURE)

VERY SUBSTANTIAL POTENTIAL FOR COMBINED SEQUESTRATION AND OFFSETS (US AND WORLD several hundred million tonne range)

ADDITIONAL GHG ABATEMENT: LANDFILL METHANE EMISSION REDUCTION

World: ≈ 30-50 Tg Landfill methane (CO_2eq ≈ 600-1000 x 10^6 metric tons/year).

Increased fractional landfill gas capture (by 25-50% ? ?) should be able to provide ≈ 100-300 or more million tonnes/year fossil CO_2eq abatement

Bioreactor landfill operation potential to mitigate atmospheric CO2 rise

I. US: Annual methane mitigation + fossil CO_2 offset calculated at 50-100 x 10^6 tonnes CO2eq (I E M report for NETL, Jan. 1999)

II US sequestration less certain, but certainly large (50 x 10^6 tonnes CO2eq/y).

III World potential probably severalfold US's. IPCC waste statistics have significant uncertainty

Total: I-III 0.5 x 10^6 or more tonnes CO_2eq/year abated

With atmospheric CO2 rise ≈ 6 x 10^9 tonnes/yr:

Appropriately managed bioreactor landfills can potentially make difference of 5% or more (reduction) in annual rise of radiative forcing total of all greenhouse gases in earth's atmosphere. Major potential for "greenhouse benefit".

ECONOMIC ANALYSIS for NETL
(I E M, 1999)

"Greenhouse Effectiveness":

FOR ANAEROBIC BIOREACTOR

USA's waste: ≈ 50-100 million tons CO_2 equivalent greenhouse gas abatement attainable within range of US $1-5/(tonne CO_2 equivalent).

This cost lower by severalfold than most greenhouse gas reduction costs examined by USDOE's Energy Information Agency (USDOE, EIA October 1998)

(Norcal Solid Waste and Golder, Inc. Concurrence on per-ton costs)

CONCLUSIONS

"CONTROLLED (BIOREACTOR) LANDFILL" TECHNOLOGY

SOLID WASTE LANDFILLS OFFER A SURPRISINGLY SUBSTANTIAL, ECONOMIC ROUTE TO BE EXPLOITED FOR CARBON SEQUESTRATION AND GREENHOUSE GAS ABATEMENT.

"CONTROLLED LANDFILLING" COULD CONTRIBUTE VERY SUBSTANTIAL RENEWABLE ENERGY

EASILY CONTROLLABLE AND OPERABLE, COMPATIBLY, WITH PRESENT LANDFILL OPERATIONS

- "GREENHOUSE BENEFIT" POTENTIAL EXTIMATED AT 3-5% DECREASE IN ANNUAL GLOBAL BUILDUP OF RADIATIVE FORCING OR "GREENHOUSE EFFECT" (THIS WORK)

- POTENTIAL TO PROVIDE 10-15% OF US GREENHOUSE GAS ABATEMENT NEEDED FOR KYOTO

- ALSO, POTENTIAL TO PROVIDE 1-2% OF US ELECTRICAL POWER AS "DISTRIBUTED GENERATION"