B.1 Bioreactor Landfills: Introduction

- <u>Conventional Sanitary Landfill (Dry-Tomb approach):</u>
 - Conventional landfill design/operation approach has evolved, over the last few decades, from "open dumping". Our approach has been to identify the individual problems and fix them by adopting
 - engineered control systems (provision of a bottom liner) or
 - changes to operation of the landfill.
 - Primary focus: minimizing groundwater contamination by
 - minimizing leachate production and
 - controlling leachate escape into the sub-surface.



Figure B1.1 Schematic Diagram of a Typical Landfill

- Objective 1 Minimize Leachate production:
 - Keep the solid waste dry by providing a cap to minimize rainwater infiltration.
 - Typically a layered system consisting of the following components is adopted ;
 - low permeable cap,
 - drainage layer, and
 - a vegetative layer.
 - With a layered cap system, it is possible to attain a percolation rate of less than 5% of precipitation.



Figure B1.2 Schematic Diagram of a Landfill Final Cover

• Objective 2: Control leachate escape into groundwater aquifers by installing a low permeable bottom liner and a leachate collection and management system.



Figure B1.3. Schematic Diagram of a Landfill Bottom Liner System (with a Composite Liner and leachate collection system)

- Outcome: Low leachate production.
 - This is advantageous because the produced leachate could be managed easily (mostly off-site treatment). If the residual field capacity is high, the amount of leachate produced could be extremely low in semi-arid environments (eg. Calgary).
 - To achieve this, the final cap should be installed as soon as the final design elevations are reached.
- Outcome: Landfilled waste remains relatively dry for extended periods of time (>50 years) after the initial placement (is this good?),

- Outcome: The breakdown of organic components is far less than its full potential, resulting in low landfill gas production rates
 - Low potential gas recovery (30-40% of available).
 - Since the production rate is low, gas recovery (for energy) may not be feasible; and may not be required (let the gas escape into the environment?)
 - Less concern with lateral migration of gas (and causing dangerous situations off-site)
- Outcome: Requires a long term plan for on site/off site gas and leachate/ground water monitoring.
- Outcome (Negative): Lose valuable space (but, a closed landfill could be converted to a park or golf course), and therefore, need to find new space every few years (even municipalities such as Calgary and Winnipeg should start looking for new space within the next 10-15 years!).
 - In developed countries, it is becoming extremely difficult to find land for new landfills within municipal limits (within acceptable hauling distances).
 - Situation in most developing countries is much worse. Landfill space is a major issue in Asian, South American developing countries
 - Reasons: Highly congested (no vacant spaces)
 - Hauling out of the cities is difficult (lack of proper roads and hauling could be extremely expensive and a burden on infrastructure and environment)

• <u>Bioreactor Landfills:</u> "are landfills where waste is being degraded in a controlled fashion"

Changes the primary goal of land? lling from "<u>storage of waste</u> to <u>treatment of waste</u>".

- This approach eliminates/minimizes two of the primary concerns with traditional landfills:
 - long period of monitoring,
 - loss of resources (if a mining stage is included, space issue could also be resolved)



Figure B1.4. Pictorial View of a Typical Landfill Bioreactor (Anaerobic)

- Goals: Stabilize the landfilled waste as rapidly as possible and recover resources from waste (energy from landfill gas)
 - (Note: an issue to be resolved: when is the waste fully stabilized?
- Landfilled waste undergoes rapid biodegradation and the landfill could stabilize within a short period of time of less than 10 years (if Stability can be defined!).
- Objectives: Provide optimum conditions for highest rate of biodegradation, by the
 - addition of moisture and nutrients,
 - control of pH and temperature
 - control of other inhibitors (ammonia nitrogen)
- Outcome: Accelerates methane production rate
 - Increase methane/energy recovery potential
- Outcome: Recover additional air space from a waste cell
 - Allow packing more before final closure of the cell by allowing waste settlement to take place (higher initial waste settlement rate?).
 - Is this acceptable?

"A bioreactor landfill could be constructed in such a manner that it can be operated in both <u>anaerobic</u> and <u>aerobic</u> modes (and may be mined for space and resource recovery)" Bioreactors operated in anaerobic mode:

- Leachate recirculated into the waste matrix by various means (pumping via horizontal trenches, vertical wells).
- Leachate could be treated prior to re-injection to remove inhibitors such as high ammonia concentration.
- Operated under optimum conditions to enhance methane generation
- The process continues until the bioreactor is fully stabilized or until gas extraction is cost effective (or converted into aerobic phase).
- "The duration of operation of a bioreactor in the anaerobic degradation mode could be determined using <u>cost-benefit analysis</u> of recovered methane".

Bioreactors operated in aerobic mode:

- Degradation of organic matter in aerobic mode is quicker than anaerobic degradation, and therefore the stabilization of the waste can be achieved in a shorter period of time.
- Achieved by the supply of air into the waste mass using an air supply network systems
- Dedicated pipes or leachate collection/re-injection systems or a gas collection pipe networks could be used to supply air with minor modifications.
- Leachate rich in nitrate (from nitrification of ammonia) can serve as an electron donor for degradation process as well.

"At the end of aerobic degradation, the decomposed waste could be mined to recover compost (can be used as daily or intermediate cover) as well as other recyclable materials and landfill space (will be available for reuse).

Bioreactors operated under HYBRID mode (Fukuoka Method):

- Accelerates waste degradation by employing a sequential aerobic-anaerobic treatment to rapidly degrade organics in the upper sections of the landfill and collect gas from lower sections.
- Results in the earlier onset of methanogenesis compared to anaerobic landfills.
- Uppermost lift or layer of waste is aerated, while the lift immediately below it receives liquids.
- Landfill gas is extracted from each lift below the lift receiving liquids.
- Horizontal wells that are installed in each lift during landfill construction are used to convey the air, liquids, and landfill gas.
- Advantages:
 - Combines the operational simplicity of the anaerobic process with the treatment efficiency of the aerobic process.
 - Expanded potential for destruction of volatile organic compounds in the waste mass (US Patent 6,283,676 B1)

Advantages of Bioreactor Landfills (over conventional landfills):

- Cost-effective recovery of resources (methane gas).
 - More methane will be produced and recovered from bioreactor landfills than from traditional landfills.
- Reduced leachate disposal costs
 - (may not be true, in all situations. Why?).
- A 15 to 30 percent gain in landfill space due to an increase in density of waste mass (settlement during cell filling)
 - greater waste density resulting in increased landfill air space available for waste disposal.
- Reduced post-closure care
 - The time period could be 10 to 15 years; compared to more than 30 years in conventional landfills- US Subtitle D landfill.
 - Similar to MBPT (mechanically-biologically pre-treated) landfills being promoted in Europe

B2 Design and Operation of Landfill Bioreactors:

Bioreactor Landfill and Conventional Landfill: Design and Operational Issues:

- Common to both types of designs:
 - Bottom liners, drainage layers, leachate collection systems
 - (since the throughput is higher, the efficiency should be higher; closer to 100% the better it is);
 - Greater concern with clogging in Bioreactors
 - Gas collection system
 - Optimum cell size;
 - Stability issues;
- Major differences:
 - Landfilled waste density
 - Landfill capacity is a function of landfill compaction density and waste settlement rates.
 - The compaction density should be lower, but initial settlement rates are higher.
 - This should increase waste density with time (leachate re-injection that depends on waste density to control permeability of waste matrix will be impacted);
 - Types of waste accepted for disposal
 - (ideally; the waste should be source separated, and only the highly biodegradable organic fraction should be accepted);
 - Leachate management

- philosophy is different. All leachate should be collected and re-injected into the cell.
- Leachate quality will be different; very high BOD in early stages with gradual decrease;
- May need to add water into the cell at early stages (if the waste is dry)
- Higher rate of biodegradation (different kinetics; k and L_o values)
- Daily and intermediate cover during filling operation (should not interfere with the leachate re-distribution within the waste mass);
- Leachate collection system should consider higher loading rates (in terms of quantity, organic matter, microorganisms). Potential is higher for clogging of leachate collection system (and the leachate re-injection system)
- Final cover could be different
 - evapotranspirative final cover layers are compatible with Bioreactors).
 - In addition, a geomembrane could be used in a final cover system to minimize air ingress during gas extraction);



- Biocovers could be more compatible (as intermediate and final covers);
 - Biocovers are specially designed covers to maximize control of fugitive emissions form landfills (typically supports the growth of methanotrophic bacteria capable of converting methane to carbon dioxide without producing harmful by-products)

B2.1 Waste Characteristics

- Waste characteristic is the main determinant in waste degradation rate and methane generation rate.
 - Large fraction of organic compounds such as food and yard waste
 - o Smaller particle size means rapid degradation rate
 - open the garbage bags during cell filling.

• Water holding capacity (WHC) of the waste (a WHC of 35-65% is considered optimum).

B2.2 Bioreactor Capacity (Size)

- Size is an important consideration in bioreactor operation in Northern Climates
- Smaller bioreactors may not produce sufficient heat to optimally operate during winter.
- Larger bioreactors (accepting waste over a longer period of time may lose methane via daily and intermediate covers, if controls are not put in place)
- Shallow bioreactors may not be suitable for leachate recirculation
- Considering all relevant issues (heat generation, leachate recirc. Etc) a minimum height of about 15m should be adopted

B2.3 Cell Size, Daily and Intermediate Covers

- Large cell size reduces quantity of materials needed for daily covers and increases the effective landfill volume.
- Daily and intermediate covers should not hinder moisture migration within the waste matrix.
 - Primary concern: lateral migration of leachate and "day lighting" as side seeps
 - Ideally, the hydraulic conductivity of intermediate cover material should be equal or higher than the waste matrix.
 - Composted, semi composted or green waste can be used.

A thin biocover (containing compost and other granular material) could be used to control methane emissions during the cell construction stage.



Figure B2.1 Compost based Biocover (30:70) at Calgary test cell

Figure B2.2 shows the effect of intermediate covers on lateral migration of leachate.



Figure B2.2 Leachate seeps

The amount of leachate escaped at this bioreactor landfill = 4000 m³

The Loma Los Colorados landfill in Chile was designed and operated as a landfill bioreactor (with leachate injection via vertical wells, leachate ponds on waste). Lateral migration started few months after the start of recirculation in 2001 and continues to-date.

Note the seeps (at the waste/intermediate cover interface)

B2.4 Bottom Liner System and Drainage Layer

- Liner Function:
 - Delay the movement of leachate into the sub-surface such that the leachate can be collected effectively. Lower the

overall permeability of the liner, higher the potential delay and higher will be the leachate collection efficiency.

- Drain leachate to collection and treatment facilities.
- Liner and Drainage System Components:
 - Natural Compacted clay and/or geosynthetic material,
 - Single material or combination of natural and geosynthetics (cost??)
 - Thickness (~ 100 cm ??)
 - Hydraulic conductivity (10⁻⁸ cm/s 10⁻⁶ cm/s)
 - Slope of the liner (1 5%)
 - Resistant to chemical attack.
 - Protect compacted clay liner (CCL) from freezethaw action
 - Cover the CCL with a single layer of waste
 - Freeze thaw increases permeability of a CCL.
 - o Ideal: Composite liner systems

Figure B2.3 compares the performance of compacted clay and composite liners



Figure B2.3 Liner efficiencies

- Leachate collection and recovery pipes
 - Size and spacing of collection and recovery pipe network
 - could use the HELP model, water-balance method to determine quantity (if proper parameter values can be used for important parameters such as Field Capacity, Hydraulic Conductivity etc)
 - Use 15 m spacing (as the maximum spacing. Design for redundancy)
 - Materials (PVC, HDPE).
 - Clogging of pipes
 - Maybe difficult to control
 - Design for redundancy!
- o Drainage layer/system
 - placed over the bottom liner to protect the liner and to facilitate flow of leachate towards collection pipes.
 - May minimize clogging of leachate collection pipes from waste degradation products
 - Use uniformly graded gravel overlain by sandy layer and/or geotextile layer (geonet?).
 - Shredded tire chips are being used, but long term performance is not known.
 - Thickness: generally 30 to 60 cm thick, but the required thickness varies depending on the hydraulic conductivity of drainage layer and liner,

surface water infiltration rate, and leachate collection frequency.

B2.5 Waste Settlement

Issues: Settlement rates are higher because of several reasons:

- starting density is low
- addition of water increases effective stresses
- increased biodegradation rates increases waste settlement rates



Figure B2.4 Change in stress with time



Figure B2.5 Settlement over time

B2.6 Waste Degradation Kinetics and Gas Production Rates

- Rates are different (should be higher).
- What are the k and Lo values for Canadian landfills? Usual practice is to use US values with slight modifications. Is this acceptable?
 - General characteristics of waste are somewhat similar.
 But, the composition is highly dependent on the location.
 No yard waste in winter (does it make sense of data from Californian landfills?)

- Landfill design/construction practices are different (US practice is highly regulated. Dry-tomb landfill data could be comparable)
- Climatic conditions (temperature, precipitation) are different (usually, this is the only variable considered by Environment Canada/Consultants)
- Traditional landfills: k< 0.04-0.05 y⁻¹ (USEPA 1999)
- Bioreactor Landfills: $k > 0.40 y^{-1}$

B2.7 Leachate Recirculation/Management System

- Additional moisture stimulates microbial activity by providing better contact between insoluble substrates, soluble nutrients, and microorganisms.
- Horizontal (at every 3 m/5 m lift) and vertical leachate recirculation systems.
- Clogging is a major issue. Struvite formation has been noted in some systems (within a period of 3 to 6 months)

Size, spacing and alignment of pipes

- No standards available.
- Difficult to model because of the uncertainties in Landfill Hydrology.
- Normal practice is to over-design and monitor leachate migration during leachate recirculation
 - (is there a fool-proof way of monitoring leachate migration?)

Treatment of leachate (before recirculation)

- Needed to minimize build-up of toxic conditions within a Bioreactor. Critical if the Bioreactor is small.
- Concern; ammonia toxicity, heavy metal accumulation
- Control:
 - ammonia stripping
 - low rate of recirculation
- Leachate recirculation rate and interval should be based on data collected from Bioreactor monitoring.
- Leachate storage and treatment (back up) if too much leachate is generated.
 - Usually a major issue in tropical climates, with high rainfall
 - Leachate treatment by evaporation in ponds and open channels (if smell is not an issue)
 - Leachate management by concentration and burning (Typical COD is about 25,000, but COD of 75,000 and 100,000 possible during early stages of leachate recirculation)
 - Use gas generated at the landfill for burning.
 - Off-site leachate treatment (in a municipal wastewater treatment plant) is the most cost-effective
 - Full-blown leachate treatment systems are expensive and may not be effective (experience in Chile, Colombia)

B2.8 Landfill Gas and Landfill Gas Collection/Management Systems

• Scholl-Canyon model can be used to calculate production rates (if the parameter values are known)

- Gas collection pipes: horizontal (at every 3 m/5 m lift) and vertical wells.
- Vertical wells can be installed on a grid pattern.
 - The distance between wells can be estimated using radius of Influence (ROI) calculations. But, this method may not work.
 - A better option is to
 - develop a coarse grid of vertical pipes and
 - undertake a surface scan (methane emissions) to identify "hot spots" and place additional vertical pipes at these locations.
 - Should be done after closure of the Bioreactor.
- Gas collection during cell filling:
 - can be done using horizontal pipes, but the quantities may not be sufficient for energy production.
 - Flaring is an option; but is not acceptable because of the toxic by-products produced by flaring.
 - The other option is to use a Biofilter to convert methane to carbon oxide.
 - A better option is to use biocovers to capture fugitive emissions (no collection).

B2.9 Instrumentation and Monitoring

• Sensors installed at every lift to monitor the moisture distribution, temperature, gas and leachate distribution and quality. Waste settlement monitored using settlement plates. The volume and quality of leachate is monitored.

B2.9.1 Moisture content

- Is one of the most important parameters
- Ideally, one should be able to measure moisture content of the waste at various locations
- Indicates the efficiency of leachate recirculation
- However, the available sensors only provide qualitative information, not quantitative info.

B2.9.2 Temperature

- Indicates biological activity in various parts of the Bioreactor. Also, indicates where cooling is required (addition of leachate). Indicate leachate movement.
- Normally not required; but is a good indicator of performance.

B2.9.3 Gas Analysis

- Gas concentration depth profile in cover soil.
- Surface flux
- Methane oxidation capacity of cover systems
- Monitoring of gas pressure during extraction phase
- Gas characteristics: to ensure methane content is acceptable for energy recovery.

B2.9.4 Leachate head on liner

A regulatory requirement. Should not exceed 0.5 m.

B2.9.5 Leachate Analysis

- Purpose: Regulatory requirements, operational control

- Parameters: N, P, Metals, pH, alkalinity, priority organics, COD and BOD

B2.9.6 Waste settlement

- Normally not required. Useful for leading-edge research.

B2.10 Regulatory Aspects

Alberta: Waste Control Regulations (under EPEA, or Environmental Protection and Enhancement Act)

- Provide specifications for Hazardous Waste and Non-Hazardous Waste Landfills
 - Class Ia landfill: accept liquid hazardous waste
 - Double liners (with one synthetic)
 - Leakage detection system
 - Leachate collection system
 - Class Ib landfill; accept solid hazardous waste
 - Compacted clay or synthetic liner
 - Leachate collection system

• Class II landfill: non-hazardous waste

- Should follow the Code of Practice
- Class III landfill: inert waste
 - Should follow the Code of Practice
- Code of Practice for Landfills:
 - CofP provides Design requirements for Class II landfills:
 - Eg. bottom liner requirements similar to Class la, except when

- There is a minimum 5m thick clay layer with a hydraulic conductivity of lxlO⁻⁸ m/s immediately below the waste, or
- Groundwater quality (because of the landfill) will not exceed performance standards specified (eg. CI- higher than 250 ppm) - Performance Based Design
- CofP also provides requirements for construction, operation
 - Monitoring, analysis and corrective action
 - Reclamation, Closure and Post-Closure care; including specs for final cover -
 - Final cover; 0.6 m compacted soil with a hydraulic conductivity of lxlO⁻⁷ m/s
 - Sub soil; 0.35 m, top soil; 0.2 m
 - Establish vegetation
 - Minimum grade of 5% and maximum of 30%
- CofPs for bigger landfills; include gas emission control systems

United States:

- Hazardous waste landfills (very strict) and
- non-hazardous landfills (composite liners or Performance Based Designs; Gas control systems)

European Union:

- Leachate control systems (for hazardous waste and nonhazardous waste landfills) are similar.
- Primary difference: Need for Biodegradable Municipal Waste (BMW) control.
 - Requirements for BMW control:
 - 25% reduction (from the base year of 1995) by Year 2002
 - 50% reduction (from 1995) by 2005 . 65% reduction (from 1995) by 2010

- Countries landfilling more than 80% of MSW, may have upto 4 years extra beyond the nominal deadline
- Promote MBPT (mechanically/biologically pre- treated landfills):
 - Mechanical treatment to remove biodegradable organics. Biological treatment; composting to reduce volatile organic content
 - Known to produce less quantities (less toxic) of emissions

Critical Review:

- major focus of North American regulations: decrease groundwater contamination potential (specify bottom liner systems to prevent leachate escape and specify top cover systems to keep the waste dry; less leachate production, less potential for groundwater contamination)
- Minor focus of North American regulations; control emission of non-methane organic compounds (NMOCs), which can cause toxic effects, into the atmosphere.
- North American regulations:
 - Control moisture entry into the landfill but organic waste is not controlled.
 - No direct control of methane emissions (indirect control only)
 - Do not control disposal of other problem wastes such as
 - Salt
 - gypsum
 - hydrocarbon contaminated soil (should be below a certain limit; 1000 ppm of Total Petroleum Hydrocarbons, TPHs, in Alberta)
- EU (European Union) Regulations:

- o Require reductions in organic waste disposal in landfills
- Reason 1: less methane emissions (Global Warming)
- Reason 2: less toxicity of leachate
- Reason 3: Rapid stabilization of landfills (less settlement; rapid end-use)
- Concerns: lack of data for 1995 (arbitrarily chosen base year)
 - Some countries (eg. UK) will have problems; Denmark, on the other hand, already meets the guidelines (disposes only 18% in landfills)
 - Based on %s; overall reductions based on weights will be high.

Performance Based Design of Landfills (Appendix A)

Key Issues to Be Addressed in Guidelines/Legislations for Landfill Bioreactor:

- Final cover material (little or no soil)
- Leachate recirculation or water addition issues.
- Head on the liner.
- Leachate breakout corrective action and groundwater protection
- Physical instability of waste mass due to increased moisture and density
 - Shear strength of degraded waste
 - Effects of moisture on shear strength
 - Waste compressibility
 - o Stability during filling operations
- Instability of liner systems
- Increase in methane emission, fires and odor in-case of a failure

Technical and Engineering Issues:

- Alternative liner design/materials for leachate re-circulation and bioreactor landfills
- Physical stability of the cover and bottom liner during and after operation
- Impacts of leachate quality, quantity, and loading on the liner system
- Times and amounts of liquids to reach field capacity
- Appropriate means for measuring field capacity
- Leachate re-circulation and its affect on the rate and extent of landfill stabilization
- Stabilization measures
- Design, operation, and performance specifications for bioreactors
- Rate, quantity, and quality of gas generation
- Interim covers used after placement to accommodate anticipated settlement
- Daily and final cover performance
- Optimum moisture content and distribution methods
- Monitoring requirements
- Bioreactor technology impacts on capping, and current closure and post-closure requirements
- Impacts of waste shredding

B.3 The Calgary Biocell Project

Recent advances in sanitary landfill research have indicated that the operation of landfills as bioreactors could be viable (Reinhart and Townsend, 1998). Waste entombment in a conventional landfill slows down the process of biodegradation by minimizing moisture entry, whereas, bioreactors speed up the biodegradation process by controlled input of moisture (i.e., by leachate recirculation) and increased cycling of nutrients and bacterial populations (Reinhart and Townsend, 1998). The operation of traditional "entombed" landfills for the sole purpose of controlling groundwater contamination is not sustainable and could be counterproductive because of the slow production and atmospheric release of CH₄, and loss of resources (e.g. material and space).

Being a relatively new technological innovation, full-scale operation of bioreactors could be fraught with uncertainties.

The *Biocell* concept involves the operation of a landfill cell as an anaerobic bioreactor with leachate recirculation to recover the full energy potential of biomass waste. In a second stage, the *Biocell* is operated in the aerobic mode to produce compost. The input of air and operation of the cell as an aerobic bioreactor enhances waste decomposition to a level where it could be mined in a third stage for resource and space recovery, thus making the landfill operation sustainable.

The *Biocell* is a novel and holistic approach to waste disposal on land; with energy recovery, GHG emission control, groundwater contamination control, and compost and space recovery as direct benefits. The *Biocell* technology could potentially eliminate CH₄ emissions associated with biomass waste; therefore it could also be termed the "zero methane landfill". This approach has the potential to revolutionize management of waste and control of associated GHG emissions in Canada, and in other countries, both developed and developing.

B3.1 Background and the Context

-1997: UofC's early research on landfill behavior:

- Lysimeter studies on leachate production rates carried out on UofC grounds.
- Indicated that a lysimeter is not a scaled-down version of a landfill; in the context of leachate production and migration.
- 1999: establish UofC/City of Calgary Test Cell
 - Two test cells (dimensions of 35m by 35 m and 5 m deep) were constructed (side by side) at the East Calgary landfill to find answers to a number of research questions.
 - We studied leachate recirculation, leachate hydrology, gas production and methane oxidation in biocovers.
 - Realized that the thickness of the test cell (5 m) is not sufficient to study the full-scale behavior of a landfill. Note: thickness determines the behavior.
- 2000-2001: discussions among City of Calgary, Stantec Consulting and UofC to develop a full-scale pilot bioreactor.
- -2001: UofC sponsored one-day workshop on sustainable landfills with additional participants from Asia, US.
- -2001-2004: Literature review, design, TAG review
- -2004: Cell construction begins
- -2005/2006: Cell filling

City of Calgary Goals and Objectives:

• Calgary Vision, 20-2020: By year 2020 Calgary wishes to "divert" 80% of MSW from landfills (current: less than 20%). The estimated life of existing landfills is about 35 years,

- The City is considering more recycling, composting and sustainable landfilling/reusable landfill cells.
- The City is looking for a "low cost solution"; will not consider major capital investments at the current time.
- The City administration/technical staff generally happy with the "status quo"; not willing to make drastic changes to their operations.

B3.2 The Cell and its Operation

- The Calgary *Biocell* is a full-scale facility, which covers an area of 100 m x 100 m with a waste footprint of 85 m x 85 m and a maximum cell thickness of 18 m.
- The *Biocell* was designed to accept 30,000 tonnes of residential solid waste (high in biomass), 25,000 tonnes of selected commercial waste (and about 30,000 wet tonnes of digested sludge). The sludge is supposed to be mixed with solid waste in place, and the resulting feedstock will be placed in three lifts of 5-6 m.
- Intermediate *biocovers* are installed to prevent CH₄ and odorous gas escape during filling.
- Collected leachate will be recirculated after ensuring the quality is acceptable.
- The produced biogas will be collected using a combination of vertical wells and horizontal pipes and used to produce energy. Gas/energy recovery will

commence after closure of the *Biocell*, and when the gas flow rates are adequate.

 A low permeable final cover will be installed to prevent gas escape from the top surface prior to extraction of biogas for energy generation.



Figure B3.1 X-sectional details of Calgary Biocell

- After several years of anaerobic bioreactor operation, air will be injected to the cell to initiate aerobic activity and convert the cell into an "in-ground composter".

- The change in operation from anaerobic to aerobic will be based on the quantity of biogas generated and economics of energy production.
- Once the decomposition slows, as indicated by gas production and temperature changes, the *Biocell* will be mined to recover resources and space.



Figure B3.2. The Three Stages of Biocell Operation

S.N	Date	Description
1	Aug 04	LBC Excavation completed
2	Sep 04	 Laid Geo-composite sub-drain over sub-grade Laid Compacted clay (75 cm thick) over Geo- composite
3	Oct- Nov 04	HDPE liner laid over clay layer
4	Nov 04	 Laid drainage pipe (HDPE-200 mm f) for leachate collection Placed gravel as drainage layer (50 cm thick) Geocomposite drainage layer laid on four slopes and drainage ditch over HDPE liner Installed sensors - Pizometer Settling plate Thermocouple Total load
5	Dec 04	Complete laying gravel layers at the bottom of <i>Biocell</i> that covers Drain Pipes and Sensors
Biocell Ready to Accept Waste		
6	April-July 05	• Waste accepted in first lift (5 m depth) of <i>Biocell</i>
7	July 05	 Laid first intermediate TBC Laid leachate recirculation and gas collection pipes
8	July- Aug 05	Monitor emissions from first intermediate TBC
9	Aug 05	 Installed sensors – Moisture Settling plate Thermocouple
10	Aug – Dec 05	Waste accepted in second lift of <i>Biocell</i>
11	Dec 05- Jan 0	• Laid second intermediate TBC
12	Jan 06	Laid leachate recirculation and gas collection pipes
13	Jan 06	• Accepting waste in third lift since 25 Jan 2006

Table 3.1 Progression of Activities (Biocell construction)

B3.4 Final Cover, Daily and Intermediate Covers



CAP STRUCTURE DETAIL

Figure B3.3 Cap details

BioCover:

- Involves the use of a granular medium capable of supporting the growth of methanotrophic bacteria capable of

converting methane to carbon dioxide without producing harmful by-products.

- Advantage: minimize fugitive methane emissions from the landfill at a low cost
- Research has shown that final covers could include a biocover layer as one of the components of a final cover system. Any soil with some organic material can be used. Important controlling parameters are:
 - o moisture content,
 - o nutrients (C, N and P),
 - o temperature,
 - o methane flow rate, and
 - o oxygen transfer to bacteria.
- Thickness of a soil-based biocover could be about 60 cm.
- The composition: 30% compost and 70% soil.
- Can biocovers be used as intermediate covers?
 - Smaller thickness (30 cm)
 - Biocover should be compatible with the waste; otherwise encourage lateral flow
 - Can partly decomposed organic waste (say unstable compost) be used? Initial results show that such material could be unsuitable for biocovers. Need fully stable compost based granular medium (higher percentage of stable compost)

B3.5 Design and Construction of Bottom Liner and Leachate Collection System



Figure B3.4 Liner details

B3.6 Settlement and Gas Monitoring (Performance of Thin Biocovers)

- -Settlement plates/sensors are located at the top of the 1st, 2nd and 3rd lifts.
- Data is being collected since August 2005 (completion of the first lift) using the sensor located at the top of the first lift.

- Over a period of about 6-7 months, we have recorded a total settlement of more than 600 mm (more than 12%).



Figure B3.5 Settlement over time (sensor at the top of the 1st lift of 5m)



Figure B3.6 Location of TBCs and sensors

Appendix A

Landfill Design for Leachate Control: The Performance- based Design Approach

Aim: ensure contaminant concentrations at the "compliance point" are within pre-determined limits.

Objective: Design/select the landfill components (landfill final cover, leachate collection system and landfill bottom liner) in such a manner, the groundwater system is not contaminated to an "unacceptable" level.

In fact, this approach ensures groundwater is not contaminated to a level that is unacceptable, but allows the designers to select the most cost effective design (not too conservative).

Approach:

• **step 1**: determine PERC

Percolation (PERC) can be determined from a water balance calculation for the top cover using the equation:

PERC=P-AET -RO-S_c - RO_S

Under steady state conditions, the amount of leachate impinging on the leachate collection system (or q) will be equal to PERC.

• **step 2**: select parameter values for liner type (hydraulic conductivity, K) and thickness (d), liner slope (tan a), drainage medium (and hydraulic conductivity) and thickness (should not exceed 0.5 m), distance between leachate collection pipes (S); and determine the leakage rate (QL) in m/s

Since q is known, now you can calculate the leakage rate for a given leachate collection system/liner design. This Q_L is the amount of

leachate escaping the landfill into the sub-surface. In fact, using Excel, you can calculate QL for a number of designs (combinations of slope, liner type and thickness, drainage material etc).

• **step 3**: determine leakage rate in m3/s, using surface area covered by the landfill cell

Now you can find the Total Quantity of Leachate entering subsurface.

• **step 4**: calculate flow rate within the groundwater aquifer below the landfill cell (info needed: aquifer thickness, hydraulic conductivity of medium and hydraulic gradient; typically about 0.1)

This is a step in which you can apply Darcy formula to find the groundwater flow rates beneath the landfill (I did not cover this in class; but is a simple extension of Darcy formula applications).

The reason you need to calculate this is to find out how much dilution will occur (to leachate contaminants) once the leachate enters the groundwater.

• **step 5**: apply mass balance to calculate concentrations of contaminants at the point of entry to the aquifer (if site specific info not available, assume no contaminants upstream of the landfill. Assume, instantaneous mixing of leachate)

Since we know the leachate flow rate (and contaminant concentrations) and the groundwater flow arte (and contaminant concentrations, if any), by applying Mass Balance you should be able to find out the concentration of contaminants at the point of entry of leachate to the groundwater system (usually, we assume instant mixing).

For each contaminant, you can write:

 $(Q_L C_L + Q_G C_G)/(Q_L + Q_G)$ = Contaminant concentration at point of entry (C_{GW1})

 Q_G = groundwater flow rate, C_G = concentration of contaminant in GW, C_L = contaminant concentration in leachate

- **step 6**: compare calculated concentrations with regulated " concentrations (eg. maximum chloride concentration = 250 ppm); if exceeded return to step 2
 - Note: calculate time taken for the stipulated contaminant to enter the groundwater aquifer. If regulations/guidelines specify a time period (eg. 25 years), use it as a design criterion.
 - Assumptions: worst case assumptions (eg. the leachate plume travels as a front, not a plume across the liner, sub-surface and in aquifer)

At this step, you would be comparing C_{GW1} for each contaminant with some criterion. If this concentration exceeds a criterion level, your design fails, if not accept the design.

Note: In this case, we are assuming the Compliance Point to be the entry point to the groundwater table. In most cases, compliance point is about 100 m downgradient of the landfill. Then we need to calculate the contaminant concentration at this point. You need to do more calculations for contaminant migration in groundwater aquifer systems. Second option: If the criteria or guideline specifies a time period, such as a 25 year lifetime, you could calculate the time of travel and compare with the criteria time period. If exceeds 25 years, exceed design, if not reject.