ENVIRONMENTAL CONTROL SYSTEMS, INC.

Summary of ECS's Aerobic Landfill and Sustainable Landfill Technologies

1 Introduction

Municipal solid waste (MSW) landfills worldwide are experiencing the consequences of conventional landfilling techniques, whereby the landfill leachate and gases that are generated from these units have been determined, in many cases, to be risks to human health and the environment. These risks are generally located near the populations which create the waste. In addition, landfilling does little to address true economic sustainability.

However, as presented herein, **Environmental Control Systems, Inc**. (USA) has developed a revolutionary, sustainable solution which addresses landfill issues in both developed and developing areas of the world. Not only does this solution protect the environment, but has many economic advantages as well.

2 The Problem with Landfills

2.1 Overview

When one hears the term "garbage" and its ultimate destination, most people think of a "dump." Traditional open dumps are quite rare today; instead trash is deposited in modern sanitary landfills. The reason for this evolution is that simply dumping garbage in a large pile creates several problems. Aside from being unsightly and foul smelling, open dumps attracted insects, gulls, rats, and other rodents. These animal "vectors" are harmful to the health of the people living nearby because they facilitate disease. Uncontrolled fires, either set or spontaneously combusting, also plagued open dumps. The most serious problem results from rain that percolates through the garbage, carrying harmful bacteria, such as *e coli* pathogens, and hazardous chemicals from the waste into the groundwater and/or nearby lakes or streams. These polluted liquids are called leachate.

As a result of these problems, open dumps were banned by the U.S. Environmental Protection Agency (EPA) in 1979, and were replaced by sanitary landfills. The sanitary landfill concept developed in Great Britain during the 1920s. The procedure entails alternating layers of compacted garbage with moderate layers of cover material. This can be soil, compost, or any other approved material. Garbage is dumped and then compacted by special bulldozers or compactors. At the end of each day when all the garbage has been dumped and flattened, bulldozers cover the fresh layer of garbage with at least six inches of soil or dirt. As this burying covers the waste, this process prevents public exposure to health hazards and temporarily reduces odor problems.

Although burying each day's waste eliminates the exposure/odor problems historically associated with dumps, there were still issues with the leachate. As such, the Resource Conservation and Recovery Act of 1992 required that all landfills operating be "lined" and equipped with leachate collection systems (LCS's). A typical liner is composed of layers of clay, gravel, plastic and synthetic material to prevent leachate from escaping. Lined landfills are also fitted with pipes to collect and drain the leachate. Although some landfills recirculate their leachate back through the landfill waste (mostly to lower their leachate offsite disposal costs), collected leachate is typically treated and discharged on or offsite.

In addition to leachate formation, decomposition is another dynamic occurring in a landfill. Inside a landfill, innumerable microorganisms are hard at work. These microbes may be fungi or microscopic bacteria. Microbes feeding on the organic matter in the landfill transform it into smaller and smaller particles. This rotting or decaying process, or decomposition, occurs very slowly in a landfill because there is very little air and moisture (and no sunlight) in the compacted layers of garbage. Lastly, since there is little to no air, the organic matter ferments, producing methane, a Greenhouse gas that has been link to global warming, as well as other hazardous air pollutants which contain toxic compounds, referred to as non-methane organic compounds (NMOCs).

Eventually a landfill reaches its maximum capacity, and cannot accept any more garbage. At this point the landfill must be closed and "capped" with layers of clay and plastic, as well as a six-foot layer of earth. As the waste slowly decomposes, it shifts and settles slightly. Thus, the land is not suitable for building homes or other development.

Thus, although we are “protected” from waste exposure and leachate through improvements in landfill design, the lack of air and water (referred to as the “dry-tomb” method) means that biodegradable materials will take many years to break down and the land is un-useable. Further, if no actions are taken once the landfill closes:

- the production of methane continues for a long-term, requiring costly management;
- although collected in the LCS, residual leachate will most likely leak from many landfills;
- landfill cracks and cap settlement will eventually expose waste and/or leachate to the public
- foul smelling odors will remain or increase; and,
- little will have been done to address sustainability.

For example, a 100-acre landfill in the northeastern United States can produce 57 million gallons of toxic leachate every year.[1] The largest landfill in the world -- Fresh Kills, in Staten Island, NY-- is over 2,965 acres and produces 4 million gallons of toxic leachate per day, or 1.5 billion gallons per year.[2] The nation's 18,500 municipal landfills that were active in the 1980s generated approximately 90 billion gallons of contaminated leachate per year. [3]Today there are close to 2,800 operating landfills. However, since waste remains in these 18,500 landfills, billions of gallons of leachate are still generated each year. Further, with respect to methane gas, emissions from U.S. landfills in 1999 were 214.6 Tg CO2 (approx. 214 billion tons), only down 1 percent since 1990.

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[1] *Criteria for Municipal Solid Waste Landfills, Case Studies on Groundwater and Surface Water Contamination from Municipal Solid Waste Landfills*. July 1988. US EPA Office of Solid Waste, EPA/530-SW- 88-040, p 3-6.

[2] Gerba, Charles P., Robert K. Ham, Anna C. Palmisano, William J. Rathje, Joseph A. Robinson, and Joseph M. Suflita. "The World's Largest Landfill: A Multidisciplinary Investigation," *Environmental Science and Technology*, 1992, v. 26, n. 8, p 34.

[3] US EPA, *Criteria for Municipal Solid Waste Landfills, Case Studies on Groundwater and Surface Water Contamination from Municipal Solid Waste Landfills*. July 1988, US EPA Office of Solid Waste, EPA/530-SW- 88-042, p 3-9.

Unfortunately, this “dry-tomb” design approach actually increases health hazards and environmental risks. Despite the effectiveness of many landfill capping systems, moisture still infiltrates into the landfill, thus increasing leachate production as described above. According to the US EPA, “liner and leachate collection [systems] ultimately fail due to natural decomposition…” Further, there have been recent issues discovered regarding the performance of some geosynthetic clay liners (GCLs) in modern landfills and attempts to correct these issues. Since landfills can produce this leachate over long periods of time, organic compounds can leak from these landfills, especially if the GCLs are compromised, thereby impacting local water resources for generations or until remediation is performed.[4]

Worse, according to US Environmental Protection Agency (EPA), there are over 50,000 inactive MSW landfills in the U.S. today. The vast majority of these landfills built before 1993 do not have protective liners, nor leachate and landfill gas collection systems to capture the harmful liquids and gases describe above. Since many of these landfills and dumps were constructed or dug directly into the ground, there are a growing number of releases of contaminants to the environment from these type landfills, despite efforts to capture the leachate (groundwater recovery systems) and landfill gas (LFG-to-energy). (See Figure 1)

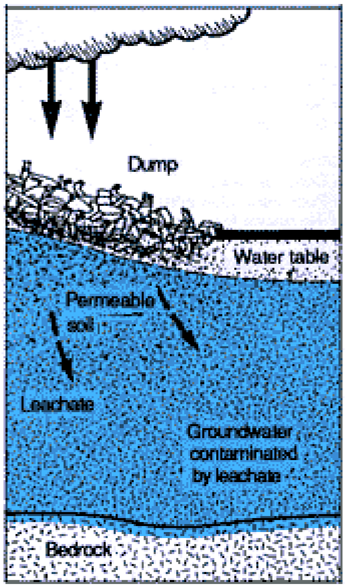

Figure 1: Leachate Production in Landfills

This is evident by the fact that, according to the EPA, 46% of all existing municipal landfills are located within one mile of drinking water wells, with 25% located within 400 meters of an active drinking water well. In California, for example, there are over 2,200 active and inactive MSW landfills. The California Water Resources Control Board has found that 83% of these are currently polluting groundwater with MSW leachate. In 1998, 100 percent of the groundwater samples taken from beneath Florida and Wisconsin landfills, benzene exceeded federal drinking water standards.[5]

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[4] *Lee, G. F., Jones-Lee, A. “Dry-Tomb Landfills.” MSW Management Jan/Feb 1996, p. 84.*

[5] Hallbourg, Robin R., Joseph J. Delfina and W. Lamar Miller. "Organic Priority Pollutants in Groundwater and Surface Water at Three Landfills in North Central Florida" *Water, Air and Soil Pollution* 1992, v 65, n 3-4.

The State of New York reported in 1997 that one-half of its 429 municipal landfills have contaminated groundwater supplies. [6]

2.2 *Burning Landfill Gas*

Some view burning landfill gas is “dirtier” than burning natural gas. Whether using an internal combustion engine or a gas turbine, burning landfill gas to produce energy emits more pollution per kilowatt-hour than natural gas does. [7]This conclusion by the EPA causes debate among those who are proponents of LFG as a “green” renewable energy source.

Further, of the ninety-four (94) NMOCs that EPA has identified in LFG, at least forty-one (41) are halogenated compounds. When halogenated chemicals (chemicals containing halogens - typically chlorine, fluorine, or bromine) are combusted in the presence of hydrocarbons, they can recombine into highly toxic compounds such as dioxins and furans, the most toxic chemicals ever studied. A review (by the County Sanitation Districts of Los Angeles County in 1998) of about 20 studies involving 76 tests at 27 facilities shows that internal combustion engines on average produce 44% more dioxin than shrouded flares.[8] Lastly, the effects of burning mercury compounds could have health-related issues.

Overall, a majority of these LFG control options are focused around handling the methane (usually by burning it) and are not focused around addressing the toxics issues. Regardless of what is ultimately done with the gas, many believe that LFG should be filtered so that the halogenated compounds are segregated. Once filtered out, these compounds should not be combusted (as that does not tend to improve the situation, but may make it worse). Opponents of combusting LFG argue that the gas should instead be handled as hazardous waste and isolated from the environment as best as is possible until there is a proven technology that can neutralize the toxins by converting the halogens to relatively harmless chemicals like salts. Although a good idea, this, too, could have significant costs.

2.3 *Landfill’s Future In Jeopardy*

In 1994, sixty percent (60%) of the nation's waste was landfilled in over 3,000 landfills. Today, due mostly to its relatively low cost, it still remains the primary method of municipal solid waste (MSW) management in the United States today. In 1999, the solid waste industry’s direct and indirect contributions to the national economy add up to $96 billion, 948,000 jobs, and just over 1 percent of the nation’s gross domestic product. [9] In that same year, 544 million tons of solid waste were processed in the U.S. Of that, 68 percent went to 3,500+ landfills, 27 percent was recycled, and 5

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[6] Concern, Inc. *Waste: Choices for Communities*. September 1988. Washington, D.C, p 7.

[7] "Methodologies for Quantifying Pollution Prevention Benefits from Landfill Gas Control and Utilization," EPA document #600SR95089, July 1995.

[8] Caponi, Frank R., Ed Wheless & David Frediani, "Dioxin and Furan Emissions From Landfill Gas-Fired Combustion Units," County Sanitation Districts of Los Angeles County, 98-RP105A.03, 1955 Workman Mill Rd. Whittier, CA 90607.

[9] Study by R.W. Beck and Chartwell Information Publishers, commissioned by the Environmental Research and Education Foundation, 2002

percent was incinerated. Based on the landfilled volume, total revenues from tip fees alone were over $16 billion, based on an average of $30 per ton tip fee.

Further, it is estimated that every dollar of revenue generated in the waste industry creates an additional $1.23 of revenue in the economy and for every one (1) job the industry creates, 1.58 jobs are created outside the industry. Lastly, the solid waste industry contributes $14.1 billion in taxes, directly and indirectly, to federal, state, and local governments. In Pennsylvania alone, the solid waste industry in that state saw, for 2002, total annual revenues of $4.1 billion to $4.6 billion, 19,451 jobs, and $643.9 million in wages.

As many agree, landfilling will continue to be needed for disposing of non-recyclable or non-combustible materials, as well as residual waste from recycling and incineration, and in some cases, organic matter. However, in many states, landfill space is running out. For example, According to a study released in 2002 by the Pennsylvania Waste Industries Association, Pennsylvania had less than 6.3 years of available disposal capacity statewide and less than two years in the eastern half of the state. Since that study, recent landfill approvals (rare events in almost any state) resulted in additional capacity at four sites. Nonetheless, the daily disposal capacity available statewide continues to rapidly diminish and Pennsylvania will face a shortfall in waste disposal capacity in eastern and central Pennsylvania in the near future unless existing landfills are expanded or new ones come on line.

Coupling the environmental problems associated with anaerobic decay, as described above, with more stringent environmental and landfill regulations, dwindling airspace, rising technology costs, and the negative public perceptance of landfills, landfilling costs as well as their opposition are on the rise. Further, as conventional technologies cannot manage the long-term impacts from landfills, the risks to public health and the environment will grow as well. Thus, in order to keep landfilling the "primary method of MSW management" at the least comparative cost for both developed and developing countries, new low-cost landfill approaches are needed.

In Europe, the practice of landfilling organic material is almost non-existent, and, thus the focus is on organic waste diversion and pre-processing. However, the pre-processing of waste is very expensive, as illustrated in the high cost of waste disposal. In developing counties, such as China, efforts are being made to provide, at least, the level of protection that landfills provided the U.S. twenty years ago. However, once these countries reach that level, they too, will eventually meet the same issues that landfills in the U.S. and Europe face today.

3 ECS's Aerobic Landfill

To meet these challenges, **Environmental Control Systems, Inc.** (ECS) has developed a new landfill bioremediation approach known as an Aerobic Landfill□□(AL). Through the aerobic degradation of MSW within a landfill, not only is there a significant reduction in the level of contaminants in the waste and leachate as well as the reduction of methane gas, but the idea of a Sustainable Landfill□ (SL) is now a reality. Not only does this immediately address the issue of sustainability for all countries, but these approaches can be readily implemented now with current resources and skill, and without the high cost of conventional technologies.

Supported by the US Environmental Protection Agency (EPA) and a number of other federal and state agencies, the AL approach is a natural, low-cost option to reduce health risks, odors, and

Greenhouse gas (GHG) emissions at landfills and uncontrolled dumps worldwide, especially where other options are not practical or economically attractive. Further, ECS's AL and SL approaches will create GHG emission reduction (ER) credits that will be of great value under an open market trading program (methane). Furthermore, combining these benefits with the possibility of landfill reuse (via landfill mining) will make landfills less harmful and will increase the potential for sustainable landfill strategies to significantly extend the life of the landfill.

3.1 Background

One of the assumptions in managing a landfill is that waste degradation is slow and that methane gas will always be produced, in many cases, over 50% by volume of the total LFG gases. However, active aerobic biodegradation processes, such as composting, have demonstrated that not only can the biodegradable portion of MSW be stabilized in a significantly shorter time frame (as compared to anaerobic conditions) but, due to the increased availability of oxygen, methane production is reduced. Further, by recirculating the leachate back into the waste and, at the same time, injecting air into the waste, the facultative and respiring bacteria inherent to the waste convert the biodegradable mass of the waste and other organic compounds to mostly carbon dioxide and water, instead of methane, with a safe, degraded humus remaining.

As the inventor of the AL and SL, ECS developed proprietary methods whereby the landfill waste is leveraged as its own treatment bed, on a large scale, such that air, moisture, waste, and nutrients are combined together within the waste, thus promoting a more rapid and effective treatment of the waste and leachate. In effect, the landfill cell serves as a large closed vessel and is managed to control leachate, LFG, and factors associated with aerobic waste composting (e.g. waste moisture content, temperature). Also, as observed in most wastewater treatment facilities, aerobic treatment processes can also reduce concentrations of certain organic compounds typically found in wastewater and leachate. Compounds such as toluene, MEK, vinyl chloride, as well as many odor-causing compounds (e.g. ammonia) are treated in aerobic lagoons, rotating beds, and fixed media systems. As the AL also treats liquids, yet on a larger scale, the need for subsequent landfill leachate treatment is reduced.

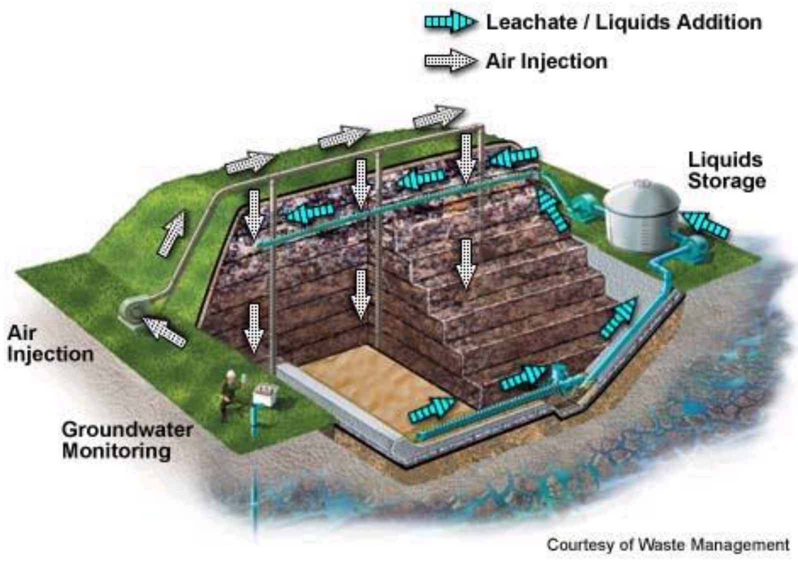

Figure 2: Schematic of Aerobic Landfill in RCRA Subtitle D Landfill

Source: http://www.epa.gov/epaoswer/non-hw/muncpl/landfill/aerobic.htm

3.2 Design

As described in ECS's patent (*US Patent Number*, *5,888,022*), the **Aerobic Landfill** (AL) is "a system and method [that] provide[s] for treating biodegradable waste material in a landfill by aerobic degradation. Waste material is deposited in the landfill and covered. The moisture content in the landfill is increased from about 40% to about 70% and a source of oxygen is injected into the landfill to drive and maintain primarily aerobic degradation of the waste material. The temperature in the landfill is increased to substantially eliminate pathogens from the waste material. The temperature in the landfill is controlled within a range of about 130.degree. F. to about 150.degree. F. to sustain the primarily aerobic degradation. Any combination of oxygen content, moisture content, and temperature in the landfill is monitored and varied to sustain and maintain the primarily aerobic degradation in the landfill."

By treating the liquid and vapor-phase organics (the primarily contributors to the waste's toxicity) in an aerobic manner, the waste is "stabilized" in a shorter timeframe than under anaerobic conditions, generally less than 4 years. In addition, the AL system (air and water are simultaneously injected into the waste) naturally reduces methane gas as well as foul "anaerobic" odors. Further, as the AL operator injects the proper portions of air and liquids to ensure that waste temperatures naturally rise and remain between 140 and 165 degrees F, the optimal composting range, there is a noticeable reduction in leachate generation. Further, not only does the AL evaporate much of the leachate from the landfill via natural heat production but this heat also kills many waste-born pathogens in a very short time.

3.3 Operation

AL systems rely on the natural process of composting; however, instead of windrow turning, the provision of oxygen to the waste mass, as well as the application of moisture is accomplished via wells installed into the waste. This addition of air and the recirculation of leachate provide the right combination of oxygen, moisture, and nutrients to the indigenous, respiring microorganisms so that they can maintain a high growth rate and metabolic activity. In each case, a reliable, well-engineering, flexible system for adding air and leachate is designed to treat the waste *in-situ*. Using readily available materials and equipment, AL systems are readily integrated into the existing landfill infrastructure.

The key to the AL's effectiveness is the proper control of aerobic conditions, whereby waste mass temperatures and moisture are maintained within optimal ranges. This is accomplished by balancing airflow and leachate recirculation into the waste mass in a manner that effectively composts and stabilizes the waste. At an AL site, the air injection system generally comprises of electric blowers (or compressors) and piping, connected to header piping. Vertical air injection wells are installed directly through the clay cap and into the waste. Each well is connected to the header piping to complete the system. (In some cases, the existing leachate collection system (LCS) can be used to provide oxygen to the waste mass as well as collect leachate during air injection.)

Leachate, collected in a holding tank or pond, is pumped into the landfill through a leachate recirculation (LR) system that is installed in a similar manner as the air system. The LR system injects leachate into each well through the intermediate clay cap while air is simultaneously injected. The leachate then percolates downward and mixed with the air that had been forced into the waste by the blowers/compressors. Leachate that is not utilized during aerobic decomposition migrates further downward into the landfill's leachate collection system (LCS), and is once again pumped to the tank, to be recirculated through the waste mass. This "closed-loop" configuration not only maximizes that potential for leachate treatment but also reduces the potential for operator exposure to leachate and minimizes operator involvement. A schematic of a typical AL system is shown in Figure 3.

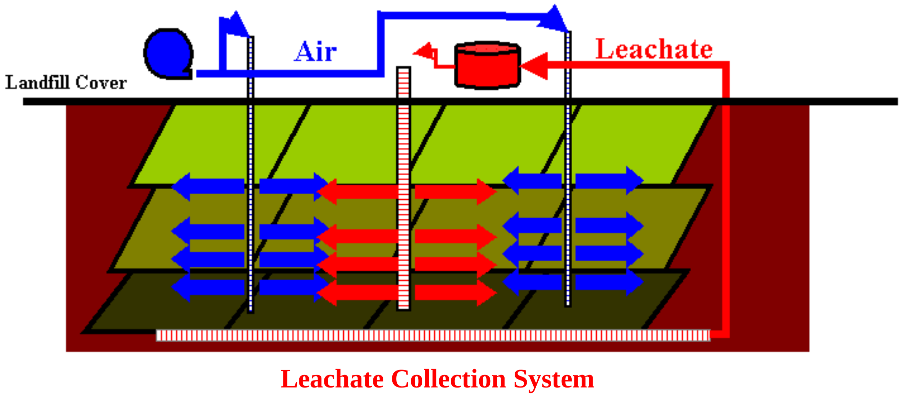

Figure 3: Typical Aerobic Landfill System Construction

3.4 Monitoring

Aerobic conditions are balanced by properly adjusting leachate flow and air delivery into the waste mass to keep the waste mass moisturized and aerated. Experienced technicians closely monitor the aerobic landfill during the startup period (2 to 5 months) to ensure safe, effective operating conditions are established. Airflow and leachate flow adjustments to each system are made based on real-time data. After the startup period, long-term monitoring can be accomplished by site personnel. Automation of system components can be implemented to further minimize the time requirements for landfill operators.

The primary goal of the aerobic landfill system is to achieve optimum waste stabilization through aerobic degradation. This is defined in terms of a stabilized organic matter, decreased concentrations of leachate contaminants, reduced methane production, and waste mass subsidence. Laboratory and field analyses provide the data needed to determine the system's effectiveness on the leachate. Direct measurements of landfill gases are used to determine the amounts of methane and NMOC production. The subsidence of the landfill waste mass is monitored by physical survey. Although, the biodegradation rate of this process can be determined in various manners, for most applications, the biodegradation rate is determined based on oxygen uptake rates, percent organic material, and waste mass temperature measurements. Upon stabilization, the waste can be excavated to examine the degree of aerobic decomposition.

For unlined sites, the impacted groundwater can be collected from existing (or new) downgradient wells and, instead of offsite treatment, injected back to landfilled waste simultaneously with air in order to allow the aerobic system to rapidly detoxify the leachate and degrade waste together. Any leachate that could migrate downward through the waste and back into the aquifer, (if it "escapes" evaporation) would be collected again by the downgradient well system. (See Figure 4)

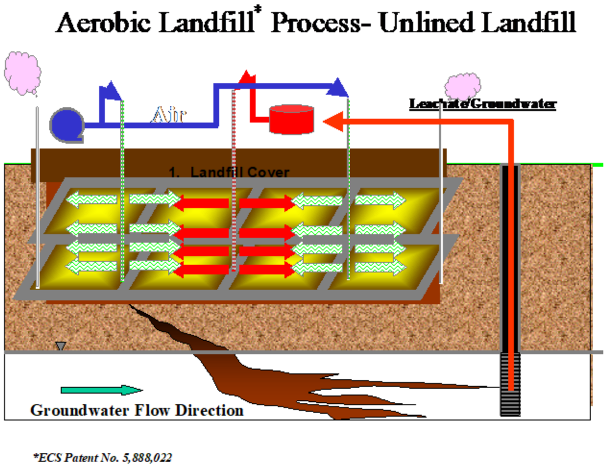

Figure 4: Aerobic Landfill Application in an Unlined Landfill

3.5 Results

Since 1997, the AL has demonstrated at a number of landfill sites: 1) significant increases in the biodegradation rate of the MSW over anaerobic processes, 2) reductions in the volume of leachate as well as organic concentrations in leachate, and 3) significantly reduced methane and NMOC generation. In addition, waste settlement was observed as each AL system degraded the organic portions of the waste mass. These benefits were obtained while maintaining an optimum moisture content of the waste mass and waste mass temperatures.

AL performance has been proven at many sites in the US and abroad. These projects confirmed that, in an aerobic environment, respiring bacteria convert the biodegradable mass of the waste and other organic compounds to mostly carbon dioxide and water, instead of methane, with a stabilized humus remaining. In addition, the recirculating of the waste’s leachate through the waste mass improved the waste’s degradation, whereby the recycling of moisture, and nutrients are continually made available to the respiring micro-organisms indigenous to the waste.

Stessel & Murphy showed that, in operating small-scale landfill test cells with pulverized waste combined with leachate recirculation and air injection, volatile solids were reduced by 60% in 40 days.[10] The results also indicated that leachate COD concentrations were reduced by 90% in the aerobic cell compared to the anaerobic control cell. In other related work, Leikam et al. (1997) indicated that methane concentrations in landfill gas could be reduced from 60% to 10-15% in 7-10 days by air injection, indicating the potential for final site stabilization. [11]

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[10] Stessel, R.1 & Murphy, R.J. (1992): 'A Lysimeter Study Of The Aerobic Landfill Concept'. *Waste Management & Research*, Vol. 10, pp. 485-503.

[11] Leikam, K. Heyer, K.U. & Stegmann, R. (1997*):* 'In Situ Stabilisation Of Completed Landfills And Old Sites'. *Proceedings*, Sardinia 97, Sixth International Landfill Symposium, Cagliari, Italy, pp. 451-462.

3.5.1 Case Study Number 1: Two Georgia AL Sites

Scaling up in size, larger AL's have been designed, built, and operated with much success. For example, at two separate landfills in Georgia (USA)[12], ECS (8 acres each) demonstrated: 1) a significant increase in the biodegradation rate of the MSW over anaerobic processes, 2) a reduction in the volume of leachate as well as organic concentrations in leachate, and/or 3) significantly reduced methane generation. In addition, waste settlement was observed as each system degraded the organic portions of the waste mass. See Table 1 for results.

Parameter	**AL No. 1 Results[13]**	**AL No. 2 Landfill Results[14]**
Biodegradation Rate	**Increased > 50%**	**Increased > 50%**
Leachate BOD_5	**Reduced by 70%**	**No BOD data**
Leachate VOCs, Metals	**Reduced by 75 - 99 %**	**No VOC data, Metals remained stable**
Leachate Volume	**Reduced by 86%**	**Significant Volume of moisture evaporated, estimate to be 50%**
MSW Settlement (ft/ft)	**Average: 4.5%**	**Greatest: 10%**
Methane Generation	**Reduced by 50 - 90%**	**Reduced by 50 - 90%**

Table 1: Summary of Overall Results

3.5.1.1. Landfill Waste Temperature and Gases

Within the AL, O_2 initially increased in the waste at system startup. In conjuncture with this, CO_2 fell initially and then rose in close correlation with O_2 consumption. When observed with the methane levels, gas readings indicated a transformation from anaerobic to aerobic metabolism: CO_2 rises as O_2 is consumed and CH_4 production falls off. At AL No. 2, oxygen uptake rates ranged from 0.167 to 0.351 mg of O2 per gram of volatile solids per hour. [15]

Further, waste mass temperatures remained relatively stable between 40^o C and 60^o C after aerobic conditions were reached. The greater the temperature, the more carbon is utilized. Waste mass moisture was above 50% (w/w) in the most active areas.

In each AL case, vapor and temperature data show that aerobic waste degradation is established and proceeds at a rapid rate. (see Figure 5) The stoichiometric relationship between aerobic carbon utilization and heat release supports this; significant amounts of carbon are converted to cellular products via aerobic metabolism.

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[12] ECS, Inc. 2002. *Draft Scope of Work for Research, Development, and Demonstration Aerobic Landfill Project, Owner Landfill*, Aiken, SC. March.

[13] ECS, Ibid, 2002

[14] Johnson, W.H. and Baker, J. , "Transformation of An Anaerobic MSW Landfill to an Aerobic Bioreactor at Live Oak Landfill" Presented at Waste Tech '99, New Orleans, February 2, 1999.

[15] Smith, M.C., Das, K.C., Tollner, E.W., Johnson, W.H, Davis, Layton, J.G. , Ibid, September, 1998

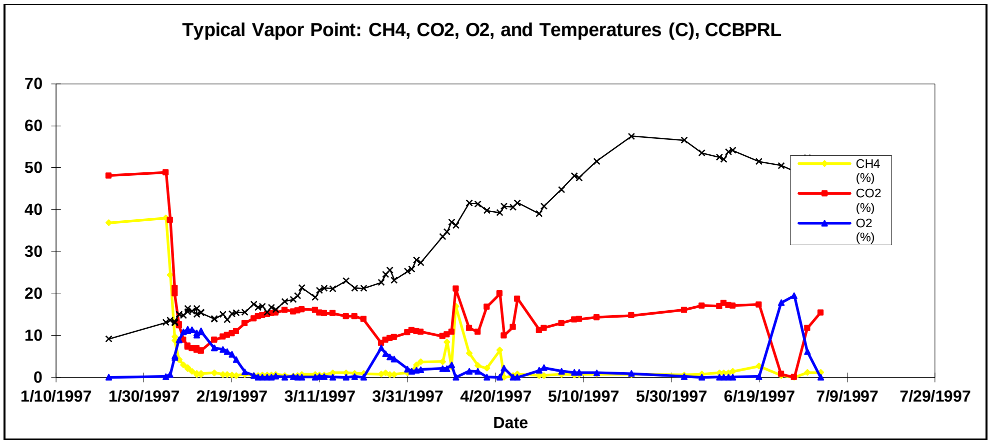

Figure 5: Example LFG Measurements at an Aerobic Landfill, Georgia (USA)

Further, the AL reduces total non-methane organic compound (NMOC) concentrations. At one AL site, three aerobic mentoring wells averaged 37.0 ppmv (as hexane). The total NMOC from the "anaerobic" or “control” well was 146.9 ppmv (as hexane), a difference of 75%.

3.5.1.2. Landfill Leachate

Prior to AL start-up in January 1997, Landfill No. 1 sent approximately 120,000 gallons of leachate each month to the local treatment plant. This leachate was pumped through the landfill’s new lift station with no pre-treatment. During the first six months after system start-up, Landfill No. 1 pumped no leachate to the treatment plant. Fourteen (14) months after start-up), Landfill No. 1 only pumped a total of 250,000 gallons to the treatment plant, a 86% reduction compared to what it would have had to treat.

With respect to leachate quality, significant reductions in VOCs and BOD were observed at Landfill 1, as shown in Table 2.

Parameter	Before Injection	After Injection
BOD (ppm)	1100	17-110
TOC (ppm)	1130	28
Iron (ppm)	110	0.3
Acetone (ppb)	1,700	120
MEK (ppb)	690	80
Toluene (ppb)	1,500	8
Methylene Chloride (ppb)	250	0
Fecal Coliforms (CFU/100ml)	1,950,000	0

Table 2: Summary of Leachate Quality Before and After Air Injection, Landfill 1 Site.

3.5.1.3. Waste Excavation and Odors

Further, after 11 months of AL operation, "aerobic" and "anaerobic" areas of the Landfill No. 1 were excavated to examine the results of the aerobic landfill. In most of the areas excavated, the waste appeared to be MSW typical of the U.S. southeast bagged and unbagged food, paper, plastic, and miscellaneous wastes. Inspection of the various types of organic wastes collected in the "aerobic" areas confirmed that the aerobic landfill rapidly degraded much of the organic fractions of MSW, similar to other aerobic composting operations, resulting in the production of a rich humic material.

In comparison, inspection of the waste samples collected from the excavations in the "anaerobic" areas confirmed little to no degradation of the organic wastes present. Also, odors from the excavations in the "anaerobic" areas had significant ammonia and sulphur components. MSW examined in these two areas had been placed into the landfill at approximately the same time.

Waste samples collected from waste excavations at an AL project at Landfill No. 2, the largest fraction (over 50%) appeared “as a suitable soil/compost material with a sufficient moisture content” (30%). [16] The compost, which passed through a 1- to 2-cm screen, was stable, with little odor. Plastic products, metals, and glass occupied over 30% of the remaining materials, with inert materials as the balance (Smith, 1998). Lignin-containing materials (e.g. wood and paper) degraded slightly. Laboratory analysis showed that soluble salts, metals, and pH were within safe ranges. Also, no pathogens were detected in the materials. With respect to the degree of compost activity, oxygen uptakes in waste samples collected from one site ranged from 0.167 to 0.351 mg per gram of volatile solid per hour (VSPH). Respiratory measurements of this type performed on compost have determined that oxygen uptake rates of less than 0.5 mg of oxygen per gram of VSPH indicate stable compost (Smith, 1998).

3.5.1.4. Waste Settlement

Physical waste surveys, taken before and during the projects, indicated cover settlement at several locations in the aerobic test area of Landfill No. 1 of up to 9 inches from a waste depth of 10 feet. For Landfill No. 2, there was in excess of 12 inches (30 cm) of settlement in most areas (10%), as measured by physical survey.

3.5.2 Case Study Number 2: Central Tennessee Site

At a six-acre AL site in Tennessee that began operations in 2000, site engineers collected waste respirometry data in 2004 that shows a less oxygen uptake per gram of dry matter of solid waste, as compared to before aeration, resulting in a 45% uptake reduction. In addition, Total Volatile Solids (TVS), Lignin, Cellulose, Biochemical Methane Potential (BMP), and Total Solids, all indicators of waste toxicity, were reduced 55%, 40%, 47%, 9%, and 4%, respectively. Also, there has been a statistically significant drop in BOD/COD ratios over the past four years. [17]

Based on this data, the waste is apparently becoming more “stabile” or less likely to release harmful gases and liquids. Thus, the leachate that is produced from this waste, much of it liquids that penetrate the soil cover (e.g. rainwater), would be less toxic. As such, the landfill may be granted a waiver by the State of Tennessee from having to construct an expensive, prescriptive capping

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[16] Smith M.C., Das K.C., and Tollner E.W., 1998 Characterization of Landfilled Municipal Solid Waste Following In-Situ Aerobic Bioreduction, *Proceedings of Composting in the Southeast, 1998* University of Georgia, Atlanta.

[17] Civil and Environmental Consultants, Inc. , Nashville, Tennessee, 2004

systems (soil, HDPE liner) Instead, only a moderate soil cover, one that allowed more percolation, could be installed.

3.5.3 International Results

Moreover, there are variations of the AL worldwide. For example, the Fukuoka Method is one aerobic approach that is being widely applied across Japan. This Method utilizes the self-purifying capacity inherent in 'nature' to stabilize waste materials (Hanashima 1999) such that; the quality of leachate improves significantly and more rapidly than in anaerobic conditions (See Figure 6). As such, it offers considerable cost advantages in not requiring secondary leachate treatment. Also, the generation of methane is reduced thus helping the prevention of global warming. Lastly, the stabilization of the waste is enhanced making it possible to return the completed landfill sites to other uses in a shorter period. The Japanese version of the AL technology is cost-effective and simple to construct and operate, allowing a high degree of freedom in the selection of materials for pipes and accessories

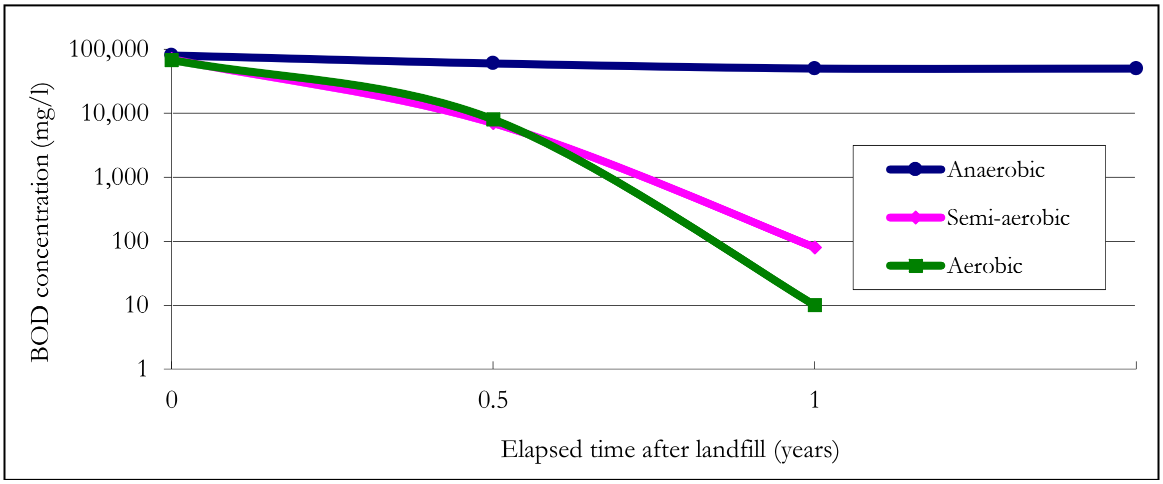

Figure 6. Results from the Fukuoka Method (Hanashima 1999) [18]

Simulation of municipal waste biodegradation in lysimeters has provided knowledge of main processes that take place in the aerated landfill. From the point of view of minimization of hazardous impact of old landfills on the environment caused by the leakage of leachates and landfill gas emission, the main aim of aeration for achieving its sustainability is the stabilization of biodegradable substances and components containing nitrogen.

Investigations carried out by Heyer et al.[19] during *in situ* aeration of the landfill in Kuhstedt (Germany) after 14 years since it had been closed, revealed that methane content in the landfill gas

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[18] Hanashima, M., 1999, Pollution control and stabilisation process by semi-aerobic landfill type; the Fukuoka method, *Proceedings of Sardinia 99, 7th International Waste Management and Landfill Symposium*

[19] Heyer K. –U., Hupe K., Ritzkowski M., Stegmann R.: Technical Implementation And Operation Of The Low Pressure Aeration Of Landfills. Proceedings Sardinia 2001, Eight International Waste Management And Landfill Symposium, Cagliari, Italy, 1-5 October 2001, Vol. Iv, 521-530, 2001.

decreased from around 50% to less than 1.5% during ca. a month since starting the aeration. In biogas samples taken from the landfill gas system installed in the landfill in Modena (Italy), around 10% methane was found after ca. 50 h of periodic aeration [20].

In landfill processes simulation the lysimeters were filled with alternately laid layers of a waste and compost mixture. The mixture of wastes contained organic waste (a composition typical of kitchen waste in the city of Łódź[21]: vegetable and fruit – 10.9%; potatoes – 21.2%; bread – 2.3%; others – 3.6%) – 38%, paper and cardboard – 25%, plastics – 17%, textiles –5%, other wastes – 15%. The waste was comminuted to the size 20-50 mm. Experiments were carried out in 4 laboratory lysimeters of working capacity 15 dm^3. The lysimeters consisted of a glass cylinder of inner diameter 150 mm and height 850 mm, closed on top and bottom with stainless steel covers, equipped with pipes for leachates recirculation, taking samples for analysis, supply and collect of gases.

Experimental studies showed that the aerobic waste stabilization was a very quick process. During a month the bed was stabilized, reaching a significant reduction of organic load indices. Aeration of the lysimeters caused a quick reduction of mainly degradable organic substance (in terms of BOD_5) and $N\text{-}NH_4^+$ and volatile fatty acids. The reduction of methanogenic potential of the landfill was even faster. The composition of gas at the outlet from the lysimeter changed and after one day already it was similar to atmospheric air.

A more frequent recirculation of leachates enhanced greatly the aerobic biodegradation. It was found that ozonation of leachates contributes to a growing reduction of pollutants in the leachates. On the other hand, UV irradiation with the addition of H_2O_2 did not increase either the degree or the rate of organic substance degradation.[22]

A decrease of methane emission from landfills to the atmosphere and at the same time guaranteeing safety in these landfills can be accomplished in different ways because of microbiological oxidation of methane by using forced aeration of landfills[23].

On larger scales, a large Arizona (USA) municipality (population 500,000) chose to use an aerobic process to address contamination at three unlined, closed landfills, totaling 18 hectares. These sites are slated for development as part of an $870 million revitalization project, aimed at stimulating business growth in the downtown area. The project involves aerobic degradation of these landfills

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[20] Cossu R., Lavagnolo M.C., Raga R.: In Situ Stabilisation Of Old Landfills: Lab Scale And Field Tests. Proceedings Sardinia 2001, Eight International Waste Management And Landfill Symposium, Cagliari, Italy, 1-5 October 2001, Vol. Iv, 531-540, 2001.

[21] Ledakowicz S., Kaczorek K.: Biodegradation Of Leachate From Municipal Landfill In Lodz Enhanced By Advanced Oxidation Processes. Proceedings Sardinia 2001, Eight International Waste Management And Landfill Symposium, Cagliari, Italy, 1-5 October 2001, Vol. Ii , 319-328, 2001.

[22] Simulation Of Aerobic Stabilisation Of Municipal Landfills In Lysimeters Liliana Krzystek[1], Anna Zieleniewska[1], Stanisław Ledakowicz[1], H.-J. Kahle[2] [1]department Of Bioprocess Engineering, Technical University Of Lodz, Poland [2]lusatian Academy Of Natural Science Lanaka, Cottbus, Germany

[23] Scharff H., Oonk H., Vroon R., van der Sloot H.A., van Zomeren A., Hensen A.: Improved methane oxidation by means of forced aeration under a landfill cover. Proceedings Sardinia 2001, Eight International Waste Management and Landfill Symposium, Cagliari, Italy, 1-5 October 2001, vol. II, 555-564, 2001

using air injection and water application to stimulate bacterial consumption of refuse. Initial project activities involved:

- review and interpretation of existing data on landfill characteristics and methane distribution;
- design of an aerobic stabilization pilot study;
- installation of LFG monitoring, extraction, and air injection wells;
- refuse characterization;
- air permeability testing and in-situ methane generation rate testing, and
- numerical modeling of the aerobic stabilization process.

These data were used in 2005 to design a full-scale application that has resulted in degradation of the waste such that redevelopment can now proceed.

Further, a Florida municipality plans to use the AL system at a closed 65-acre landfill as part of a "Brownfield" administrative initiative- the reuse of abandoned property. Once the system has degraded the waste, the City can choose from a number of post-aerobic landfill strategies, including: 1) site redevelopment whereby the landfill surface is regraded with new soil cover materials to meet geotechnical standards for commercial activities; and/or 2) waste mining whereby the degraded waste can be excavated and the humus/soil components separated from the remaining non-degraded matter for agricultural or construction (e.g. road) use. The remaining non-degraded matter (plastics, glass, and metal) can be used in the production of plastic wood products to provide additional income for the landfill.

3.6 Support from US EPA

As outlined in their "Options for Reducing Methane Emissions Internationally Volume I: Technological Options for Reducing Methane Emissions." (EPA 430-R-93-006, July 1993), EPA recognizes that:

> *"Aerobic designs increase the rate of decomposition, reduce the emissions of harmful and odorous trace gases, and improve the quality of leachate. These advantages are significant in terms of pollution reduction and the reclamation of landfill sites."*

With this in mind, landfills can be rapidly degraded, thus protecting the environment more effectively. In addition, smaller, more economical landfills cells can be built and then treated by an AL process. As a result, operating and closure costs can be reduced. Further, worldwide project data supports EPA's view on the AL as a methane control strategy, citing from the same source:

> "*landfills can be designed to be aerobic so that less methane is produced…. Aerobic designs increase the rate of decomposition, reduce the emissions of harmful and odorous trace gases, and improve the quality of leachate. These advantages are significant in terms of pollution reduction and the reclamation of landfill sites. More advanced designs* [ECS] *….. have achieved reductions of over 80 percent……."*

The US EPA Office of Research and Development (ORD) has recognized this approach as an emerging 'Tier II" LFG control technology and that it *"is expected to become a prime candidate technology for landfills in the U.S. and elsewhere that can not generate LFG in sufficient quality or* *quantity to economically recover the associated energy.”*[24] As such, EPA's Landfill Methane Outreach Program (LMOP) has recognized ECS’S AL approach as a suitable methane mitigation technology at certain solid waste landfills. Other agencies and trade groups such as the US Department of Energy and the Solid Waste Association of North America (SWANA) recognize the potential benefits of the Aerobic Landfill and have begun research programs to promote this approach.

4 The Sustainable Landfill

As the AL helps detoxify the waste and reduces hazards such as methane gas and waste-borne pathogens, landfills can now be safely mined and “recycled.” Developed by ECS as the “Sustainable Landfill” (SL), (*US Patent Number 5,564,862*) this approach leverages the AL to meet waste sustainability goals. Instead of building large mountain of waste, the waste is placed into the fewest number of cells within the current or planned landfill “footprint.” As the cells are sized to occupy only enough area to mange the incoming waste stream and built closely together, each cell (four or five in total, depending on the waste characteristics, and waste degradation time) will experience one of these activities in a “rotating” sequence as shown in Figure 7.

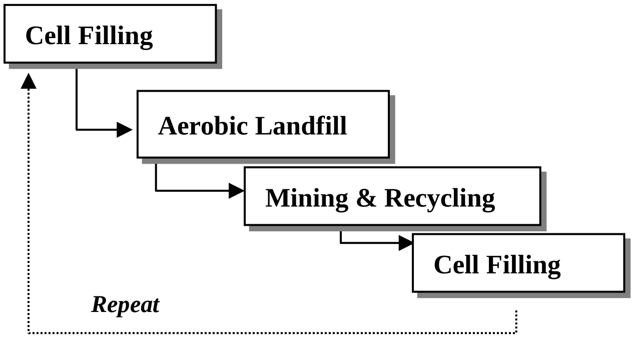

Figure 7: Sustainable Landfill Cycle

As illustrated in Figure 8, the first SL cell □is filled with waste. The next cell has been filled with waste and an AL system installed. The waste in the remaining cells have either been stabilized or are under excavation. The open cell that has been mined is being filled again.□ (Note that in each case, methane production is either minimal or non-existent.)

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[24] “Emerging Technologies for the Management and Utilization of Landfill Gas” (EPA Document Number EPA-600/R-98-021)

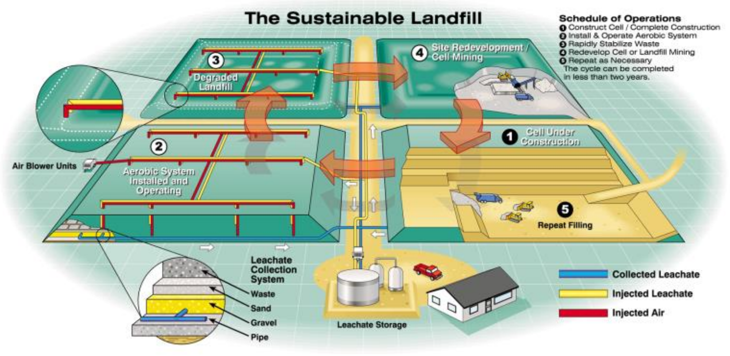

Figure 8: The Sustainable Landfill – Example Layout

Cell Filling

Each cell is filled with MSW using conventional waste placement techniques. Base waste layers are built to accommodate heavy vehicles and built up with waste and soil covers, as required, to elevations and dimensions that are less that planned. The last layer is covered with soil (or stockpiled soil/compost generated from a previous SL mining event) and readied for installation of the reusable AL system.

The Aerobic Landfill Phase

Once the waste is in place, the AL wellfield and support system is installed. Leachate, stormwater, and/or other moisture source are pumped into the landfill waste through the landfill cover via liquid injection vertical wells. Air and moisture are pumped simultaneously into the wells using the same type of wells. Once active, the AL process is closely controlled to ensure treatment stays within target ranges. The leachate collection system is common to all cells thereby maximizing the volumes of moisture that can be used and minimizing material usage.

Waste Excavation, Recycling, and Cell Reuse

Once the waste has rapidly degraded, the waste is then excavated and processed by screening, tromelling and/or mechanical or manual sorting. Of the total waste stream processed, previous results have shown that approximately 50 percent of the separated matter is a soil/compost matter that can used as daily cover for future SL applications, road materials, or agricultural purposes (since it will be pathogen-free). The remaining percentages (especially plastics) can be used as feedstock for low-grade plastic wood products or as a fuel source. Metals can be separated for recycling and resale. Remaining inert and degraded materials can be placed in a less expensive construction/demolition (Construction/Demolition) waste landfill cell. In the end, the cell is emptied and, if needed, rehabilitated. New waste is then placed into the cell and the former cover soils (previously stockpiled) are reused as a “new” cover. Conventional excavation, screening, and separations technology keep operating costs to a minimum.

5 Environmental Benefits

There are a number of environmental benefits of the AL and SL ranging from the evaporation of leachate to the detoxification of waste to the virtual elimination of methane, an explosive Greenhouse Gas (GHG). Other benefits are described below.

5.1 Reduced Risks to the Atmosphere

As presented above, methane and NMOCs are reduced via the AL. In addition, LFG-to-energy (LFGTE) systems that drop below economic production thresholds may be shut down. However, the landfill may still produce methane gas in sufficient amounts that LFG collection and management may still be required. In these cases, the landfill may have to purchase and supply fuel to burn low volumes of LFG.

To address this, the LFG collection system could instead easily be reconfigured into an AL system (using the same blowers, piping, controls) to rapidly degrade the remaining organic matter and LFG, thus eliminating long-term, costly LFG management.

According to the US EPA, global methane emissions from MSW landfills range from less than 20 to 70 Teragrams (Tg) per year[25]. Assuming that an AL or SL system will reduce 50% of the 20 Tg of methane produce from these landfills each year (conservative), on average, the total reduction of methane over the next seven years could equal approximately 70 Tg, (or 70,000 Gg). Using a global warming potential (GWP) of 23, (23 times harmful as carbon dioxide) this equals to over 430 million metric tons CO2 equivalent of methane.

5.2 Reduced Risks to Water Resources

The AL improves leachate quality (lower BOD and VOCs). Thus, should leachate leak from the landfill to water resources, the overall risk would be lowered. Further, VOCs typically found in LFG can contribute to poor groundwater quality as they migrate via the subsurface. As the AL reduces VOCs in the vapor phase, the risk is further lowered.

5.3 Reduced Risks to Human Health

Many waste-born pathogens such as *escherichia coli* and *microbacterium tuberculosis*, are killed at the high temperatures observed in the AL (>50 degrees C). Since the AL operates for extended periods at these temperatures, the potential exposure to pathogens during waste excavation and processing is lowered. In addition, pathogen reduction in the leachate can occur.

5.4 SL Process

The application of a SL allows, during the mining stage, for an inspection of the landfill floor and liner systems. If a breach has occurred, it can be remedied, rather than allowing contaminants to leak as would under a conventional approach. Further, if a cell is either being filled, under aerobic conditions, has undergone aerobic decay, or being mined or filled, the generation of harmful leachate or methane will have been reduced.

6 Economic Benefits

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[25] Bingemer, H.G. and Crutzen, P.J.. 1987. The Production of Methane From Solid Wastes. *Journal of Geographic Research* 92 (D2): 2181:-2187

6.1 Economic Sustainability

In 1999, the solid waste industry's direct and indirect contributions to the national economy add up to $96 billion USD, 948,000 jobs, and just over 1 percent of the nation's gross domestic product. [26] In that same year, 544 million tons of solid waste were processed in the U.S. Of that, 68 percent went to 3,500+ landfills, 27 percent was recycled, and 5 percent was incinerated. Based on the landfilled volume, total revenues from tip fees alone were over $16 billion USD, based on an average of $30 USD per ton tip fee.

Further, it is estimated that every dollar of revenue generated in the waste industry creates an additional $1.23 USD of revenue in the economy and for every one (1) job the industry creates, 1.58 jobs are created outside the industry. Lastly, the solid waste industry contributes $14.1 billion USD in taxes, directly and indirectly, to federal, state, and local governments. In Pennsylvania alone, the solid waste industry in that state saw, for 2002, total annual revenues of $4.1 billion USD to $4.6 billion USD, 19,451 jobs, and $643.9 million USD in wages. Eliminating the indirect contributions to the national economy and focusing on landfilling, the portion of the solid waste industry that The Company's bioreactor technologies will potentially affect is estimated to be over $40 billion USD.

However, the cost of landfilling is rising, in terms of both economic and environmental impacts. Of the U.S.'s 53,000 or more active inactive, abandoned, or closed MSW landfills, (3,000 operating/ 50,000+ closed) many sites are required to meet stringent (and expensive) rules on addressing potential and confirmed impact to the environment. As presented above, millions of dollars are required to control landfill gas emissions. According to the EPA, landfills that were active in the 1980s generated approximately 90 billion gallons of contaminated leachate per year. This is an important issue considering that 46% of all existing municipal landfills are located within one (1) mile of drinking water wells, with 25% of them located within 400 meters of an active drinking water well. As such, many states are reporting landfill cleanup actions.

Further, in certain areas of the country, landfill space is running out. For example, according to a study released in 2002 by the Pennsylvania Waste Industries Association, Pennsylvania had less than 6.3 years of available disposal capacity statewide and less than two years in the eastern half of the state. Since that study, recent landfill approvals (rare events in almost any state) resulted in additional capacity at four sites. Nonetheless, the daily disposal capacity available statewide continues to rapidly diminish and Pennsylvania will face a shortfall in waste disposal capacity in eastern and central Pennsylvania in the near future unless existing landfills are expanded or new ones come on line.

When compared to the benefits, the AL and SL can provide, in many cases, the most cost-effective option for landfill management which can address many of these concerns. The combined costs of AL piping, blowers, controls, licensing, and operation, have shown to be much less that than the overall financial benefit provided. Further, as the construction and operation of these approaches are site specific, overall costs can be less. Lastly, instead of budgeting for separate systems or programs (one each for odor, gas, and leachate control), only one system is required.

The total savings with respect to life cycle costs for an AL or SL include the following

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[26] Study by R.W. Beck and Chartwell Information Publishers, commissioned by the Environmental Research and Education Foundation, 2002

- limited (or no) new landfill construction and/or expansions
- recycling and sale of aerobically treated materials
- establishes MSW sustainability
- reduced landfill operational costs
- leachate disposal costs are eliminated
- opportunities to receive additional waste (and revenue)
- only one (1) central facility needed
- reduced LFG management and associated costs
- millions of dollars in avoided costs and increased revenue
- creation of spin-off industries and jobs (e.g. waste recycling)
- increased value in adjacent real estate;
- can provide political benefits-eliminates “not in my back yard (NIMBY)”issues
- creation and sale of GHG emission reductions (ERs), described below

As shown above, combinations of cost saving benefits can add up. At many U.S. sites, the key economic savings related to an AL or SL are mostly related to 1) the avoidance of costs associated with landfill expansion and 2) closure and post-closure care cost reductions. In developing countries, the AL and SL approach can reduce the costs of new sites, health programs, groundwater remediation, and odor control. Further, impacted properties can gain an increased value.

Thus, the AL and SL can be applied at the following types of sites:

- small, medium, and large landfills
- operating/ open / active sites
- closed, uncontrolled and unlined dumps
- landfills where LFG-to-energy is not economical or feasible
- sites with LFG or groundwater impact
- landfills in developing countries with health issues
- older, abandoned “Brownfield” sites

As such, landfills can experience, financial savings related to the AL include: 1) limited (or no) new landfill construction or expansions, 2) reduced operational costs, 3) elimination of leachate disposal costs (due to natural AL evaporative effects), 4) increased revenues from additional waste receipt, and 5) reduced LFG and odor management costs. In addition, older, unlined landfills that are remediated by the AL now can have a higher real estate value. Lastly, “stabilized” waste (waste with inherently lower risks) provides the owner the opportunity to seek relief from closure/post closure obligations.

For example, at the six-acre AL site in Tennessee, presented earlier, a more “stabilized” waste, may preclude a prescriptive, composite (soil/plastic) capping system. Upon approval by regulatory agencies, an alternate soil cap may be allowed. This could reduce the landfill’s capping cost by over $1 million USD. Also, as presented, the landfill has documented significant odor and methane gas reduction (over 90%) as well as the treatment (and disposal avoidance) of over 8 million gallons of leachate. This will save the landfill over $1.2 million USD. With the LFG system now not needed, the combined net savings at this relatively small landfill is, so far, over $2.2 million USD. Avoidance of the potential remediation costs, for this site, is estimated to be in the millions of dollars.

At a planned AL in California (USA), an analysis of two proposed landfill management alternatives for a closed, unlined landfill was recently performed to compare their respective financial aspects. The first alternative was the conventional long-term operation of the landfill under anaerobic conditions. For at least the next 30 years, the landfill owner would spend over $300,000 USD per year to manage LFG, remediate groundwater, and perform other post-closure activities. This would equal over $9 million USD with the consideration of interest and cost-of-living increases.

The second alternative is a four-year AL application. Using present-value analysis and a modified benefit scoring system, it was recommended that an AL system be conducted for it would not only be the lower cost of the two alternatives, but would also avoid million of dollars of post-closure and groundwater remediation costs and it ranked higher, from a benefits perspective, than the anaerobic approach with respect to lowering long-term risks, litigation, and future site remediation, and increasing the potential for site re-development/ re-use.

6.2 Overall Economic Impact

Although the AL and SL approaches are feasible for most landfills, their overall economic impact is difficult to define for the many potential benefits are site-specific. However, assuming that only 10% of the 450 million tons of waste that are sent to landfills annually were sent to landfills that were converted to SL operations, the total additional revenue from tip fees over the next 10 years would be **over $112 million USD**, assuming a 25% life extension (2.5 years) and an average tipping fee of $30 USD per ton. A 50% life extension would add **over $224 million USD** in tip fee revenues. Further, millions of more dollars could be saved by the reduction or avoidance of new landfill construction and/or expansions, and the offsets in avoided leachate treatment.

Moreover, after a 4-year, $2.5 million USD (avg.) AL application at only 10% of the nations 50,000 closed landfills, these landfills could net **over $2.5 billion USD** in post-closure savings over the next 30 years, if such costs were $100,000 USD per year at each of these landfills.

7 Sustainable Landfill – Case Study

The Cumberland County Solid Waste Improvement Authority (CCIA) in southern New Jersey is embarking on the permitting and construction of the largest aerobic landfill project in North America, (3 million cubic yards) with construction scheduled to begin in spring 2004.

Once the landfilled waste is degraded in 3 to 4 years via ECS's AL, the CCIA will recapture valuable landfill airspace and refill the landfill cells for this and subsequent sections of the landfills, as the sections are sequentially aerobically treated and mined, thus creating a "Sustainable Landfill."

The CCIA owns and operates a landfill, recycling center and support facilities in its 357.5-acre (143 ha) Cumberland County Solid Waste Complex (CCSWC) in Deerfield Township, New Jersey. The Authority opened the landfill in 1987 to serve the residents and businesses of the 14 municipalities of Cumberland County, New Jersey. Since the demise of flow control, the Authority's landfill has been an active market participant and has been successful in maintaining a cost competitive landfill serving Cumberland County and the surrounding areas.

The CCSWC landfill was first permitted in 1985 and consists of six Phases covering 75.5 acres (30. 2 ha). The general orientation of the landfill is shown in Figure 9. The landfill was most recently repermitted in October 2000 for a vertical expansion to a maximum elevation of 212 feet MSL (63.6 m), approximately 130 feet (39 m) higher than the surrounding area. Adjacent to the landfill is an on-site leachate pretreatment facility and leachate storage tanks and lagoons. The facility has a capacity to allow the landfill to be open through 2021 (10 million cubic yards or 7.6 million cubic meters) at its presently projected disposal rates (200,000 tonnes per year). The landfill is required to treat its annual production of over 17 million gallons (76.5 million L) of leachate per year before it is transported offsite for secondary treatment.

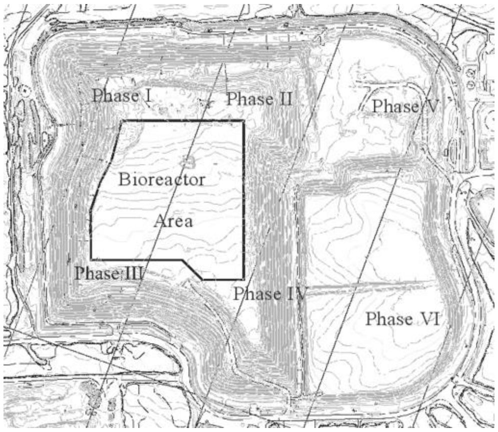

Figure 9: Cumberland County Solid Waste Complex in Deerfield Township, New Jersey

7.1 Project Goals

Presently the Authority's facility life is projected to last through 2021. The CCIA's chief goals in this AL project are to extend the life to beyond 2021 within the permitted area (and if necessary a small adjoining area for a small lateral expansion), avoiding the expense and risk associated with planning a larger expansion or siting a new landfill, increasing disposal capacity, and reducing overall life cycle costs. In addition, the CCIA will use the AL to reduce closure and post closure care obligations and to maintain protection to the environment and reduce the landfill's impact on natural resources whenever possible.

With the AL essentially degrading the readily and moderately degradable fraction of the waste and the moisture content being controlled as part of the system operation, the system is designed to promote landfill mining. With the recycling of the metals and plastics and the beneficial use of the decomposed organic fraction as either cover material or for off-site beneficial use, the landfill life can be significantly extended.

7.2 Applicability to CCIA

With the AL approach as the foundation, smaller cells containing MSW can be constructed, filled with waste, aerobically treated, and then mined in a few years all within a reduced landfill boundary.

Presently, the first four phases (Cells 1 through 4) of the permitted six phases (Cell 6) have been filled to a plateau elevation about 65 feet (19.5 m) below the permitted top elevation. The plateau, or "tabletop", is about 11 acres (4.4 ha) and is well suited to be the location for the first application of the AL.

The AL system will encompass approximately 600 air injection wells and 200 liquid injection and venting wells. This portion of the project will take approximately 1.2 million cubic yards (0.912 million cubic meters) of waste though the aerobic degradation of the readily and moderately degradable portion of the waste and exhume the waste for processing using available landfill mining technologies. The waste will be processed to remove recyclable materials and the remainder will be further processed to sort the non-degraded non-recyclable portion of the waste from the soil like material consisting of degraded organic waste and cover soils that is expected to be the bulk of the remaining material.

The purpose of this phase is to establish the time, energy and liquid requirements needed to degrade the waste at this particular site and the site-specific recovery characteristics of the degraded waste from landfill mining activities. The next step is the ultimate goal of this project, the implementation of a continuing cycle of landfilling, aerobic treatment of waste, landfill mining and reuse of previously used disposal areas.

In the case of the CCIA's landfill, the AL/SL approach has been modified to reflect existing conditions. The decomposition is expected to have the effect of flattening the exterior slopes. This would enable the exterior side slopes adjacent to the tabletop area to be the next stage to undergo aerobic treatment. Exhumed material will be processed within lined areas and the composted material will be used as cover and stockpiled for future use. Once the exterior slopes of the first four cells have been stabilized and excavated, the area will be refilled in subsequent smaller cells consistent with the small cell approach of the Sustainable Landfill. The actual timing and sequencing will be dependent on the site-specific decomposition rates observed during AL system operation. There will be an ongoing assessment of decomposition through settlement monitoring as well as temperature monitoring throughout the well field. When the settlement and elevated temperatures diminish, the cell will be considered completed and excavation can begin.

7.3 How the CCIA Benefits

The total savings with respect to life cycle costs for the CCIA relate mostly to closure and post closure care cost reductions and the avoidance of costs associated with landfill expansion or siting a new landfill. Operational costs for the AL are higher and there is no potential for cost recovery from collection and use of landfill gas in aerobically treated portions of the landfill. However, the cost savings from closure and post closure care are significant, and risks will be reduced. As stated previously, the remaining waste material is relatively inert and non-putrescible. A financial benefit model (see Figure 10) indicates that **an additional $350 million USD over 50 years** can be realized using the SL.

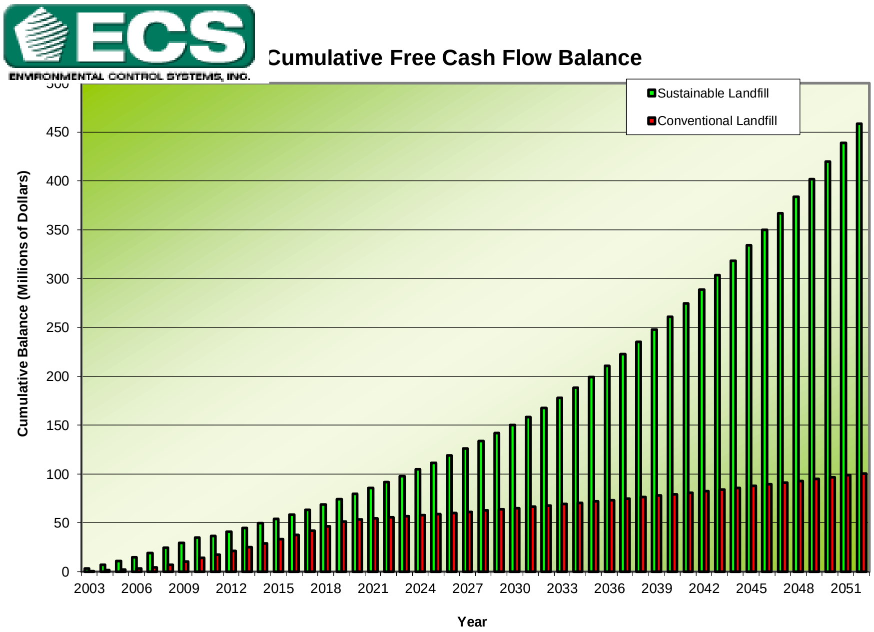

Figure 10: Projected Additional Revenue

Further, via the SL, active gas collection is not applicable for the post-closure care period, and the landfill may be treated as a relatively inert mass, thus a less elaborate cover system may be applicable such as the New Jersey Class III landfill cover of two feet (0.6 m) of vegetated soil. The relatively inert nature of the waste will also impact leachate quality, potentially reducing the amount and types of treatment necessary to achieve the applicable discharge limits. Additionally, since leachate volumes are reduced via evaporative effects, the costs for leachate treatment will be significantly reduced.

8 Project Licensing and Execution

Since 1997, ECS, a South Carolina-based small business, has invested over $4 million and conducted extensive research in this developing technology (www.aerobiclandfill.com). Further, ECS works closely with qualified engineering firms to design and operate the AL in accordance with ECS's AL and SL patents and the client's needs.

ECS's staff also has vast experience in both government and private sector businesses, including marketing, contract and program development work with the federal, state, and local agencies. ECS works closely with out clients to share our valuable knowledge and to integrate these patented technologies into respective programs in a cost-effective manner. Through mutually-beneficial licensing programs not only do our Licensees have full rights to current and future use of these technologies, but ECS also provides protection on its patents. Additionally, our Team provides technical assistance to users to ensure their safe and effective application.

ECS AL and SL technology licenses are available on either a regional basis or for individual countries. Our licenses are customized for each client and are generally based on: 1) their interest in a given regional, such as large cities, counties, states, prefectures, provinces, or portions thereof 2) the number of landfills in the selected area, and 3) market conditions.

ECS projects typically include the following steps and contracting scheme:

- Technology licensing - ECS
- Site assessment and characterization – ECS, AL Designer, via Professional Contract
- AL design and permitting – ECS, AL Designer, via Professional Contract
- AL installation – Owner Bid Process
- AL operation – AL Operator, ECS, Bid or Professional Contract
- Data collection and analysis - AL Operator, ECS, Bid or Professional Contract
- Project completion and report - AL Designer, Professional Contract
- Post AL site redevelopment and/or cell reuse- Landfill Owner

9 Summary

The Aerobic Landfill and Sustainable Landfill approaches are a natural, low-cost option to mange MSW landfills worldwide. Combining the benefits of aerobic degradation with the possibility of landfill reuse (via landfill mining) will make landfills less harmful and will increase the potential for sustainable strategies to significantly extend the life of the landfill, increase revenues, and make the world safer for future generations.

Successful implementation of AL and SL initiatives will help enhance many nations' goals of updating its MSW management procedures. This will improve environmental quality and raise the people's living standard and to assure sustainable development of society both in urban and rural areas.