Public Health, Groundwater Resource and Environmental Protection from MSW Leachate Pollution by Single and Double Composite Lined Dry Tomb Landfills

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With increasing recognition that a minimum design US EPA Subtitle D dry tomb landfill with a single composite liner is a fundamentally flawed approach to achieving protective municipal solid waste (MSW) management, that at best only postpones when groundwater pollution occurs, there is need to consider how Subtitle D landfilling can be accomplished and protect public health, groundwater resources and the environment for as long as the wastes in a dry tomb landfill will be a threat. The issues of the inability of minimum design Subtitle D landfills to provide true long-term protection have been reviewed by Lee and Jones-Lee (2005a). This review contains extensive references to the literature on this topic. One of the most important aspects of developing a protective landfill is the approach used for the design, operation, closure and implementation of postclosure care for as long as the wastes in the landfill will be a threat. Lee and Jones-Lee (2005b) have recently summarized the closure and postclosure issues that need to be considered in establishing protective closure plans and implementing postclosure care of dry tomb landfills.

Problems with Single Composite Lined Landfills

Presented below is a brief summary of the problems with single composite lined dry tomb landfills of the type that are being approved under US EPA Subtitle D regulations. Additional information on the issues summarized below is provided in Lee and Jones-Lee (2005a).

Wastes will be a Threat Forever. The basic problem with Subtitle D landfilling is that the wastes in a dry tomb landfill will be a threat to generate leachate that can pollute groundwater for a very long period of time, effectively forever.

Eventual Failure of the Liner System. The single composite liner system allowed in a minimum design Subtitle D landfill has a finite period of time that it can be expected to keep leachate from passing through it, leading to groundwater pollution. While it is not possible to reliably predict when the composite liner system will fail to collect all leachate that is generated in a landfill when moisture is allowed to enter the wastes through the landfill cover, it is clear that the wastes in a dry tomb landfill will still be a threat to generate leachate after the single composite liner system has deteriorated to the point that it no longer functions as an effective liner.

Unreliable Groundwater Monitoring. Another significant problem with a single composite lined landfill is that the groundwater monitoring system allowed by the regulatory agency, composed of vertical monitoring wells spaced at hundreds of feet apart or more at the point of compliance for groundwater monitoring, has a low probability of detecting leachate-polluted groundwater when it first reaches the point of compliance for groundwater monitoring. This means that offsite, adjacent property groundwater pollution will likely occur before the failure of the landfill liner system is detected. Lee and Jones-Lee (1998) have reviewed the problems with the typical groundwater monitoring systems being allowed at Subtitle D landfills.

Inadequate Postclosure Funding. The failure of the US EPA/US Congress to meaningfully address the significant error that was made by Congress in developing RCRA, of only providing for landfill minimal postclosure monitoring and maintenance funding for 30 years after closure, and no assured funding for the very long period of time that MSW in a dry tomb landfill will be a threat to generate leachate, is another of the flawed components of Subtitle D landfilling. Without assured funding for landfill monitoring and maintenance and the eventual Superfund-like cleanup of the polluted groundwaters that will occur, there can be a significant public health threat, loss of groundwater resources and damage to the environment before governmental agencies take action in the new Superfund program that will have to be developed for remediation of Subtitle D landfill-polluted groundwaters.

Leachate Collection and Removal System Problems. Conceptually, during the active life of a landfill (when wastes are being deposited in the landfill), any moisture (water) that enters the open part of the landfill, upon contact with the wastes, generates leachate (garbage juice) that passes down through the wastes until it reaches the leachate collection and removal system. The key component of this system is a plastic sheeting layer (flexible membrane liner, FML) in the composite liner. The leachate that is generated in the wastes enters the porous layer of the Leachate Collection and Removal System (LCRS), eventually reaching the plastic sheeting layer of the composite liner. It then flows on the sloped plastic sheeting layer to a collection pipe and to a sump where it can be removed by pumping. So long as the plastic sheeting layer is free of holes, the LCRS can be effective in collecting all leachate generated in the landfill. However, the LCRS can have defects at the time of construction and most importantly over time, the plastic sheeting in the composite liner deteriorates and develops holes that allow the leachate that reaches the plastic sheeting to pass through the holes into the underlying clay layer of the composite liner. Lee and Jones-Lee (2005a) have reviewed the literature on the currently known reasons for plastic sheeting liner failure.

If the clay layer in the composite liner is in intimate contact with the plastic sheeting (which is difficult to achieve) the area of penetration of the leachate through the clay is limited. If, however, the plastic sheeting has folds or other areas where it and the clay are not in intimate contact, the leachate that passes through the plastic sheeting spreads out over the clay and a much larger area of leachate passage through the clay layer occurs. According to Subtitle D regulations, the maximum head (depth of leachate above the clay layer) allowed on any location of a landfill liner is one foot. This would normally occur near the leachate removal sump since this is the low spot in the liner system. However, the LCRSs are subject to clogging due to biological growths, chemical precipitation and accumulation of fines derived from the wastes. This clogging can occur at any location in the LCRS, leading to an accumulation of leachate on the liner upgradient from the point of clogging. If the upstream area above the clogging has holes in the plastic sheeting, leachate can leak through the holes at a greater rate than if the clogging did not occur. As discussed by Lee and Jones-Lee (2005a), back-flushing of the LCRS will not necessarily remove all of the clogging that can occur in the LCRS.

Clay Liner Integrity. The rate of penetration of leachate through the clay layer is dependent on the permeability of the clay layer, its thickness and the leachate head. Under normal conditions, based on Darcy's law, one foot of leachate head will penetrate through a new, properly installed clay liner with a permeability of 1 x 10^{-7} cm/sec, at the rate of about 1 in/yr. In addition to advective transport through the clay layer of the composite liner, there is also diffusion-based transport through the clay layer. This is especially important for geosynthetic clay liner (GCL) systems due to their very thin character.

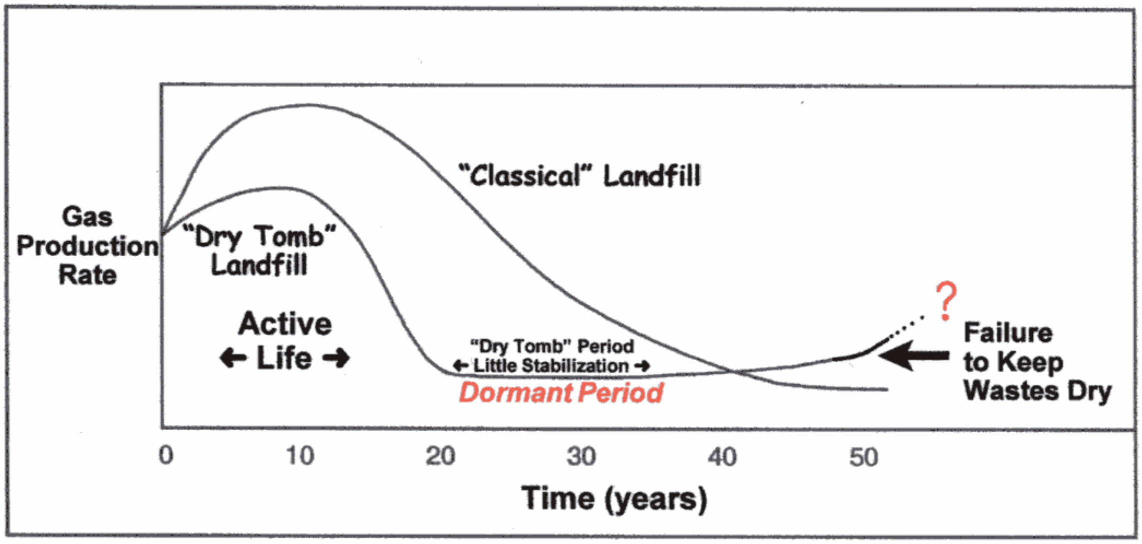
There are several reasons why the initial design characteristics of clay layers in a composite liner are not maintained. One of the most important is desiccation cracking of the clay layer associated with unsaturated transport of water that is added to the clay to achieve compaction of the clay layer during its construction. The loss of this water from the clay will lead to much greater permeability than that achieved at the time of development of the clay liner.

Another problem with some clay liners that are based on bentonite type clay is that, in the sodium form, the clay is in a swollen state. However, in the presence of calcium-rich leachate, the calcium can substitute for sodium on the clay and cause it to shrink and possibly crack. This issue is especially important for composite liners that use GCL layers instead of two feet of compacted clay as the clay layer in a composite liner. Lee and Jones-Lee (2005a) have reviewed the information on the numerous problems with compacted clay layers in landfill composite liners.

Landfill Cover Integrity is Key to Protection of Public Health/Groundwater/Environment. Overall, a single composite liner in a landfill will eventually fail to prevent leachate that is generated in a landfill from passing through the liner. However, once the landfill is closed and the required US EPA Subtitle D landfill cover is installed over the wastes, the supply of moisture to the wastes is shut off, and leachate generation will become very low to insignificant. This is a significant aspect of achieving a true "dry tomb." According to Subtitle D requirements, the landfill cover is to be no more permeable than the landfill liner. In order to achieve this level of control of moisture entering the landfill, a plastic sheeting layer is installed in the landfill cover. In principal, precipitation that falls on the surface of the landfill cover penetrates through the vegetative topsoil layer and the cover soil layer until it reaches the plastic sheeting layer of the cover. Once it reaches the sloped plastic sheeting, it flows over the top of the plastic sheeting to the side of the landfill where it is allowed to be discharged to the ground outside of the landfill.

A properly installed plastic sheeting layer in the landfill cover can effectively shut off the supply of moisture to the wastes that can generate leachate and landfill gas. A properly constructed and maintained Subtitle D landfill cover will cause the landfill to enter a "dormant" phase where little or no leachate and landfill gas is generated (see Figure 1). The dormant phase will continue as long as the plastic sheeting layer in the cover is maintained and prevents moisture from entering the wastes. However, the plastic sheeting layer in a landfill cover is subject to many stresses that can cause it to develop cracks that can allow moisture to enter the wastes and generate leachate. While it is not possible to repair the landfill bottom liner since it is covered by wastes, in principal it is possible to repair the cover and therefore keep the wastes dry. However, detecting the location of failure in the plastic sheeting layer of the cover is not readily done since it is buried under several feet of soil and fill material that are placed above the plastic sheeting layer as part of constructing the landfill cover system.

Figure 1. Evolution of Gas Production in Classical and Dry Tomb Landfills



Adapted from Lee and Jones (1991)

For those landfills that are in the dormant phase of postclosure, the failure of the plastic sheeting in the cover will be indicated by increased leachate and/or landfill gas production. A dry tomb landfill that does not enter the dormant phase with little or no landfill gas and/or leachate production, and continues to generate substantial leachate and landfill gas, has an inadequate cover over the wastes where the plastic sheeting layer is allowing moisture to enter the wastes. This is a clear indication of the need to repair the plastic sheeting layer in the cover.

About 15 years ago, two companies developed leak detection systems for determining when the plastic sheeting layer in the landfill cover has failed (see Lee and Jones-Lee 1995). The adoption of a leak detectable cover could result in being able to readily detect when the plastic sheeting in the landfill cover has developed defects that would allow moisture to enter the landfill that would generate leachate. This approach was not adopted by regulatory agencies, since it would commit landfill owners to have to operate and maintain the landfill cover detection system forever. There is the mistaken belief by landfill owners that somehow the long-term potential threat of dry tomb landfills will not lead to groundwater pollution. It is unfortunate that regulatory agencies have yet to face up to and adequately address the long-term threat that dry tomb landfills represent, and develop changes in Subtitle D landfilling to adequately prepare for the inevitable failure of the landfill liner system and cover, the unreliability of groundwater monitoring and the grossly inadequate assured postclosure funding being allowed in today's minimum design Subtitle D landfills.

The key to providing protection of public health, groundwater resources and the environment in a dry tomb landfill is the adequacy of postclosure monitoring and maintenance of the landfill.

Since the dormant phase will continue well beyond the currently required postclosure care funding established in Subtitle D, there is obvious need to change Subtitle D so that postclosure care funding will be available to adequately monitor and maintain the landfill so long as the wastes in the landfill can generate leachate and/or landfill gas when in contact with water.

Characteristics of Double Composite Lined Landfills

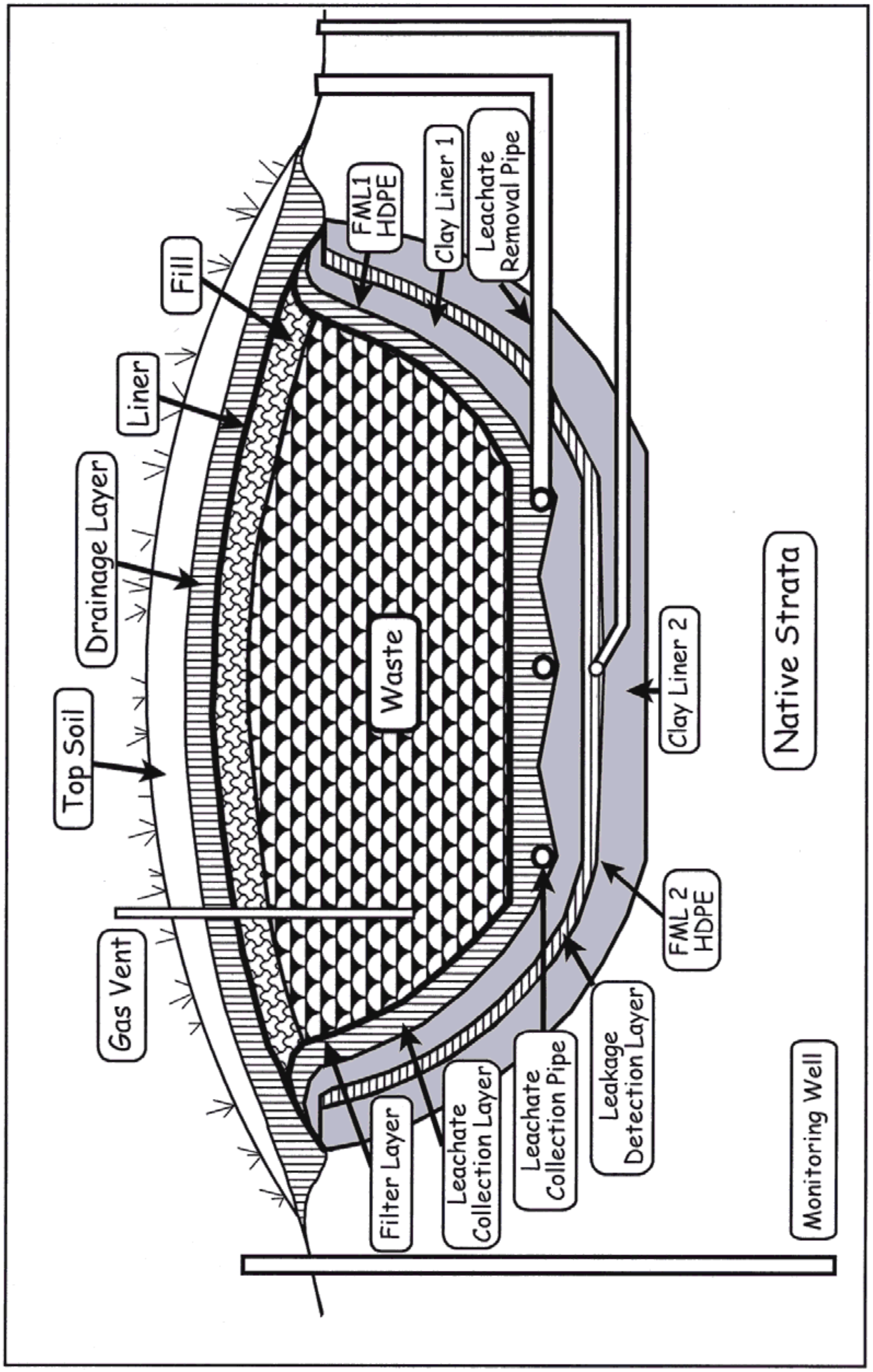
While the potential problems with Subtitle D landfills have been understood since the late 1980s, little effort has been made by the US EPA and most states to address these problems. However, several states, such as New York, New Jersey and Michigan, require that all MSW landfills be double composite lined. In the 1980s Pennsylvania adopted a single composite liner with an additional plastic sheeting layer that underlies the composite liner. This additional plastic sheeting layer, as well as the lower composite liner in a double composite lined landfill, is part of a leak detection zone to indicate when the upper composite liner fails to prevent leachate from passing through it. Subsequently, several other states or parts of states, including parts of California, have adopted double composite lined landfills for disposal of MSW, and are finally starting to require that new MSW landfills be double composite lined. Figure 2 presents a cross-section of a typical double composite lined landfill.

Developing a dry tomb landfill based on a double composite liner system can address several of the significant deficiencies of a single composite liner. The most important is the ability to detect when the upper composite liner begins to allow leachate to pass through it. The presence of traces of landfill leachate, as indicated by chemical analysis in the fluid present in the leak detection zone between the two composite liners, is the signal that the upper composite liner is failing. In time the lower composite liner will also fail to prevent leachate from passing through it. While it is possible that the lower composite liner will deteriorate more rapidly than the upper composite liner, it is likely that even if this occurs, the lower composite liner will be sufficiently reliable to transport some leachate to the sump of the leak detection zone and thereby indicate that the upper composite liner has failed. It is important to not rely on the lower composite liner as a landfill containment liner, but instead its function should be that of serving as a pan lysimeter for the landfill, as part of the monitoring system for detecting upper composite liner failure.

As discussed by Lee and Jones-Lee (1995), action must be taken at the time that leachate is first detected in the leak detection zone, to repair the cover plastic sheeting layer to stop moisture from passing through the cover. Taking this action will require that funds be available to find and repair the defect in the plastic sheeting layer of the cover to stop moisture from entering the wastes. Without assured postclosure funding beginning in year 31 after closure and throughout what could be the infinite postclosure period when funds will be needed, there is substantial likelihood that, when the landfill cover and liners fail, the groundwater pollution that will occur will go undetected until it pollutes offsite private and/or public water supply wells.

Developing a landfill with a double composite liner, without assured funding for *ad infinitum* monitoring and maintenance of the landfill, is not protective of public health, groundwater resources and the environment. The development of assured funding should be done as part of developing the disposal fees at the landfill. The additional fees collected should be placed in a dedicated trust fund of sufficient magnitude to address all plausible worst-case failures of the

Figure 2
Double Composite Liner Landfill Containment System



landfill containment and monitoring systems, as well as to provide for remediation of polluted groundwaters that could occur at the landfill.

Alternatives to Dry Tomb Landfilling

Presented below are several alternative approaches to the current dry tomb landfilling of MSW.

Allowed Attentuation/Dilution. The potential for pollution of groundwaters that are serving as a domestic water supply source could be minimized if the siting of landfills required that at least three miles of aquifer existed between where wastes are deposited and the property line of the adjacent property. No water supply wells would be allowed to be developed in this buffer zone. This approach was adopted by the Province of Ontario, Canada. Since the development of large production wells on adjacent properties near the landfill could change the direction of groundwater flow, it will be important that several miles of buffer land be required around the landfill. This buffer land is also needed to dissipate the adverse effects of airborne releases (odors and toxic gases) from a landfill during its active life.

It is inappropriate to allow public or private landfill owners to use the groundwater resources underlying adjacent properties to dilute the leachate-polluted groundwaters. For many aquifer systems, landfill leachate-polluted groundwaters are attenuated/diluted sufficiently to be a minimal threat to groundwater-based water supplies within several miles of the landfill. Basically this approach would be protective of groundwater quality by allowing part of the aquifer to be used as part of Subtitle D landfilling to protect groundwater quality. Adopting this approach would require that landfill owners acquire a three-mile buffer zone in the direction of groundwater flow. This distance is based on the finding that MSW landfills have been found to pollute groundwater by landfill leachate at distances of over one mile. The use of the aquifer to attenuate/dilute the leachate-polluted groundwater that will occur at Subtitle D landfills should only be allowed where the aquifer is well-defined and readily characterized. Fractured rock, limestone and former alluvial areas with sandy lens aquifers typically would not be suitable for allowed attenuation/dilution, because of the inability to adequately characterize/monitor the aquifer and the limited attenuation/dilution and long transport conditions that can occur.

For those situations where groundwater pollution is allowed under a landfill owner's property, a comprehensive groundwater monitoring system should be required. The reliability of the landfill applicant's proposed groundwater monitoring system should be evaluated by an independent panel of experts that do not derive incomes from working with landfill applicants. This monitoring system will need to be operated and maintained forever. Therefore, as with current Subtitle D dry tomb landfills, assured postclosure funding will be needed forever, in order to protect groundwater quality.

Bioreactor Landfills. While it was understood at the time that they were proposed that dry tomb landfills would not likely be a protective approach for management of municipal and industrial wastes, the US Congress and the US EPA failed in the 1980s to prevent the development of the dry tomb landfilling approach. Further, action still has not been taken by the US EPA to correct the significant error that was made in adopting the dry tomb landfilling approach. During the past 10 years there has been increasing interest in converting dry tomb landfills to bioreactors, where moisture (leachate) would be added to the landfill to promote landfill gas and leachate production. In principal, if properly conducted, the addition of moisture to a landfill would greatly shorten the period of time that the landfill would be a threat to public health, groundwater resources and the environment. However, as discussed by Jones-Lee and Lee (2000), there are several potential problems with the addition of moisture to a landfill, which must be considered in order to protect public health, groundwater resources and the environment. Simply adding leachate to a minimum design Subtitle D landfill can lead to increased groundwater pollution due to increased leachate generation.

The unreliability of detecting landfill liner failure by groundwater pollution monitoring associated with minimum design Subtitle D landfills, makes addition of leachate to this type of landfill highly questionable. However, a double composite lined landfill with its liner leak detection zone provides sufficient increased reliability in detecting composite liner failure to permit the development of a protective bioreactor landfill. One of the problems with converting an existing dry tomb landfill to a bioreactor landfill is that much of the wastes in today's landfills are deposited in plastic bags that are crushed but not shredded. This will hide some wastes from the added moisture and thereby delay the decomposition of the wastes that are inside the crushed plastic bags. This means that the wastes in a dry tomb landfill that is converted to a bioreactor will still be a threat to generate leachate and landfill gas for very long periods of time – i.e., until the plastic bags decompose. Jones-Lee and Lee (2000) recommend that a bioreactor landfill be developed using shredded MSW. Bioreactor landfilling will work best on new double composite lined landfills using shredded wastes.

Landfill Mining

Lee and Jones-Lee (1995) have discussed the potential benefits of the use of landfill mining as a means of controlling groundwater pollution by double composite lined dry tomb landfills. They recommend that, when the upper composite liner in a double composite lined landfill is failing to prevent leachate from penetrating through it (as detected by leachate being found in the leak detection zone), if the landfill owner does not want to replace those portions of the cover that are failing to prevent leachate from being generated (at that time and repeatedly in the future), the owner be required to exhume the wastes from the landfill by landfill mining. As discussed by Lee and Jones (1990), landfill mining has been shown to be effective for recovering landfill space. There are, however, a number of potential problems with it that would have to be addressed in order to protect those near the landfill from airborne releases of hazardous chemicals, odors, etc.

Conclusion

The fundamentally flawed technology of minimum design single composite lined Subtitle D dry tomb landfills mandates that this approach to landfilling be immediately terminated for all new and expanded landfills. Instead, all new landfills should be double composite lined using shredding of the non-recyclable components of the wastes. Initially, leachate could be recycled through the landfill to ferment and leach the landfilled wastes. After the landfill gas production rate has become very low, clean water washing of the wastes should be practiced to remove residual leachable components. This approach will produce a stabilized waste residue in a short period of time that will no longer be a threat to public health, groundwater resources and the environment.

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