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# "Dry Tomb" Landfills—The Past, Present, and Possibilities

The implications of modern sanitary landfill technology has led to what are known as "dry tombs" and presents a few possible alternatives that have the potential to achieve the same results.

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The promulgation of EPA's Subtitle D regulation (40 CFR Parts 257 and 258—Solid Waste Disposal Facility Criteria) has significantly impacted sanitary landfill design, construction, operation, and closure over the past two decades. Developed under the Resource Conservation and Recovery Act (RCRA) of 1976, and in response to 1984 Hazardous and Solid Waste Amendments to RCRA, the rule sets minimum criteria for modern solid waste landfill in seven basic areas: location restrictions, facility design, operations, environmental monitoring, financial assurance, corrective action, and closure and post-closure care. The facility design provisions provide prescriptions for the makeup, installation, and operation of key landfill design features, including a composite bottom liner and leachate collection system to minimize leakage of leachate, and a final cover system at the time of closure to minimize infiltration of precipitation and other liquids into the waste mass.

A relevant consequence of the Subtitle D regulations was that restricting liquids from infiltrating into the waste mass—including precipitation, stormwater runoff, and leachate—created conditions in which the organic waste components decomposed, compressed, and generated gas much more slowly than compared to a "wet landfill." Waste in a dry tomb landfill takes more time to decompose (stabilize), thereby extending the post-closure management and monitoring period by several years, or even decades.

Questions and concerns relating to the potential downsides of dry tomb landfills have been raised by landfill owners, operators, regulators, and designers since Subtitle D was promulgated. In response to these concerns, and with appreciation for the advances that have taken place in landfill technology, EPA promulgated the Research, Development, and Demonstration (RD&D) rule in 2004 under Subtitle D. RD&D was an interim measure that allowed for an introduction of liquids and recirculation of leachate on alternative bottom liners, as well as other waste treatment approaches, to facilitating waste degradation, accelerating gas generation, minimizing leachate treatment efforts, increasing the rate of waste settlement, and reducing post-closure activities.

However, as of March 2014, EPA indicated that there were only were 30 active RD&D projects in 11 approved states, and one project on tribal land. This statistic suggests that dry tomb landfilling is still practiced widely, despite the apparent disadvantages and concerns raised by numerous parties. Fortunately, EPA proposed in the November 13, 2015 Federal Register to allow directors of states with EPA-approved RD&D programs to increase the maximum term for RD&D permits from 12, to 21 years at 40 CFR 258.4(e)(1), to provide more time to support research into the performance of bioreactors, alternative covers, and run-on systems.

### Remembering the Past: Subtitle D (Did the "D" Mean Dry Tomb?)

Under the original Subtitle D rule, state regulatory agencies were required to adopt the prescriptive facility design approach or something no less restrictive, with some flexibility to consider the influence of local conditions such as climate and hydrogeology. The vast majority of new landfills and landfill expansions in the US adopted regulations similar to Subtitle D, including a composite bottom liner (or equivalent) and a relatively impervious final cover system.

As described in Subparts C, D, and F to 40 CFR Part 258, the prescriptive bottom liner and final cover components and features of a Subtitle D landfill include the following (from bottom to top):

- Composite bottom liner (dual components in direct and uniform contact)
  - Lower compacted soil layer 24-in. thickness with a hydraulic conductivity (K) $<1x10^{-7}$cm/sec, or geosynthetic clay liner (GCL) alternative
  - Upper (primary) Flexible Membrane Liner (FML), 30-mil thickness, or 60-mil if HDPE
- Leachate collection system (LCS)
  - Designed to maintain a maximum 30-cm depth of leachate over the liner
- Waste mass cover material
  - Minimum 6 in. of earthen material (daily cover) or alternative thickness to control disease vectors, fires, odors, blowing litter, and scavenging
  - No liquid waste, except for leachate and gas condensate, which are allowed as exclusions
- Final cover (under Closure and Post-Closure Care) to minimize infiltration and erosion
  - Minimum 6-in. "erosion" layer for supporting plant growth
  - Minimum 18-in. "infiltration" layer with hydraulic conductivity less than or equal to bottom liner system or natural subsoils, or no greater than K<1x10-5cm/sec, whichever is less
  - Begin closure activities within 30 days of final receipt of waste; complete within 180 days following beginning of closure

### Avoid the "Bathtub Effect"

One of the main reasons EPA included a relatively impervious cover system is described in the Federal Register dated October 9, 1991. Basically, comments provided to EPA prior to finalization of the Subtitle D rules indicated it was important to avoid the "bathtub effect," wherein leachate could infiltrate through the cover at a higher rate than it could be removed. This requirement was interpreted to require a flexible membrane liner (FML) component in the final cover similar to the FML component in the bottom liner.

In addition to the material and performance requirements, the composite bottom liner and final cover were often physically or mechanically connected at or near the waste boundary so as to essentially encapsulate or entomb the waste. Encapsulation of the waste mass had the positive effect of virtually eliminating the potential for exposure of waste to the environment, as well as the potential for leachate to leak through the bottom liner system. It also had the negative effect of reducing the amount of liquid, whether in the form of precipitation and/or stormwater runoff, that might otherwise infiltrate into the waste mass and either flow through the waste to be collected as leachate, or be absorbed by the waste itself. Encapsulation restricted moisture content changes in the waste mass from external influences, creating a "dry tomb."

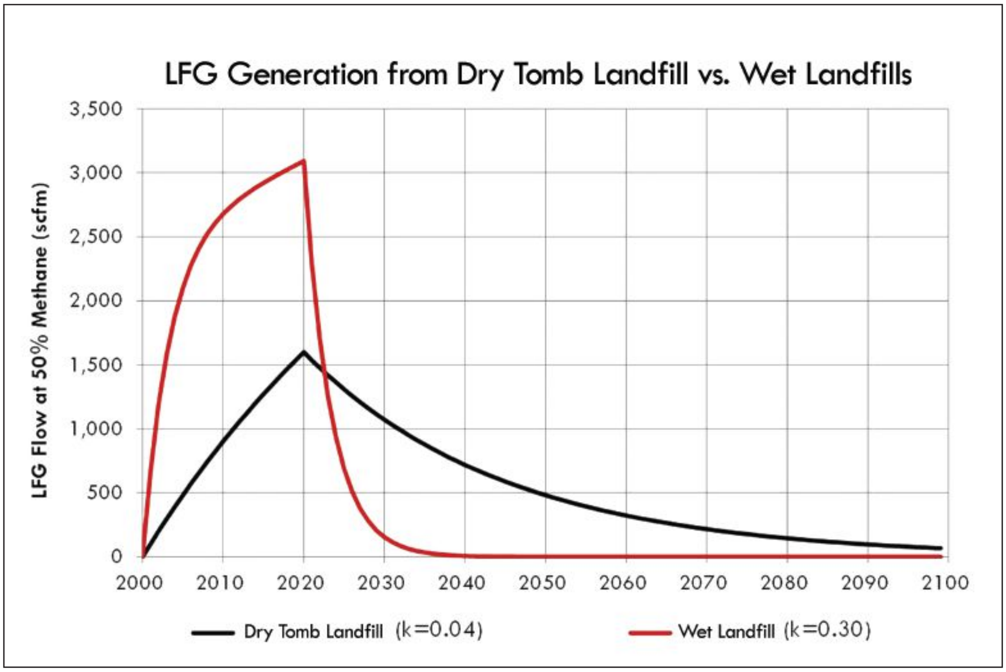


Figure 1

Far from waste being technically dry (zero moisture content), most sanitary landfill waste includes significant organic matter and other moist materials, and may receive direct precipitation during active filling phases. Results of field testing of municipal solid waste in non-arid regions generally finds moisture contents in the approximate range of 10 to 30% (wet weight basis), which is below field capacity (F'c), and well below saturation (S), which means that most waste has the capacity to absorb additional liquid. Therefore, the term dry tomb is relative and merely suggests that the moisture content is lower than it would otherwise be if the waste were not encapsulated below and above, and did not include daily soil cover layers that tend to compartmentalize the waste.

### The Present: Current Industry Practice

Subtitle D allows for disposal of leachate and gas condensate on the prescriptive bottom liner (i.e., recirculation), and the RD&D rule expands upon this by allowing leachate recirculation on alternative bottom liners. But, many solid waste facilities have chosen not to practice recirculation, and some have terminated recirculation for various practical and/or economic reasons. Despite numerous technical articles and papers addressing the downsides of the dry tomb landfill, little has changed since 1991; the standard Subtitle D bottom liner and final cover system as described above are still widely followed by the states and the solid waste industry, with some variations and adaptations.

Complicating the situation, as noted above, is that conventional practice often includes welding the final cover to the bottom liner system, or alternatively, the cover FML is extended laterally to beyond the lateral limits of the bottom liner (such as in perimeter anchor trenches). This technical detail prevents stormwater runoff from backflowing into the landfill and keeps landfill gas from escaping at the perimeter or edges. It also precludes moisture content changes over time to the following sources:

- direct precipitation or runoff that might leak through the final cover through pinholes or small defects,
- water that is consumed and/or produced as part of methanogenesis/waste degradation processes,
- moisture removal from landfill gas collection (gas condensate), and
- leachate and gas condensate that is disposed (recirculated) within the waste.

Under these conditions, the waste mass will theoretically lose moisture over time, and the waste will become drier than at the time of placement unless the moisture losses are replenished from infiltration, or from recirculation of liquids back into the waste mass. Given the importance of liquids in maintaining conditions necessary for anaerobic decomposition of organic matter in the waste, and which directly impacts gas generation, reducing the moisture content over time has potential downsides:

- the waste decomposition process slows down and as such, the time needed to achieve waste stabilization is lengthened indefinitely;
- landfill gas production is slower which may have ill effects on its utilization;
- post-closure care periods may have to be extended; and
- landfill settlement is slower.

The rate of gas generation from a Subtitle D covered "dry tomb" landfill would be expected to slow down over time compared to generation at landfills not so encapsulated. This would not only have ill effects on gas utilization; it lengthens the time needed to achieve biological or chemical waste stabilization indefinitely, extending the post-closure period for decades.

The latter point is suggested by conventional Landfill Gas (LFG) generation models, including EPA's Landfill Gas Emissions Model (LandGEM), which allow a waste decay rate variable (k value) to be adjusted to account for the effect of moisture on LFG generation rates. Gas curves for a moderately sized MSW landfill under standard (k = 0.04) and RD&D Rule bioreactor (k = 0.30) conditions are shown in Figure 1 and which clearly show the period of gas generation for a dry tomb landfill extending for decades beyond a wet landfill. Unfortunately, LandGEM does not have a mechanism to account for changing moisture conditions over time using a varying rate of waste decay (k value), and the effects of changing waste moisture on LFG generation at individual sites' are poorly understood and difficult to quantify.

### The Future: Alternative Possibilities

With the proposed time extension of the RD&D rule from 12 to 21 years, and the clear economic advantages of stabilizing the waste mass more quickly with the introduction and management of liquids, why are we still building so many dry tomb landfills? Why are we not taking advantage of the RD&D rule or Subtitle D's allowance for recirculation? Is it because we have not yet reached the 30-year post closure care endpoint to realize that the waste has not stabilized, and that post closure care may be extended?

The answers, in part, are that designing, constructing and operating a dry tomb landfill is relatively straightforward, widely accepted as standard practice and carries limited risk—it is the comfortable approach. Designing a landfill to promote faster stabilization of waste by allowing liquids introduction, or applying alternative design and operational approaches requires more thought and effort, more documentation, technical demonstrations, operational evaluations, and some degree of experimentation.

However, the benefits of accelerated gas generation/collection, additional recoverable airspace, and more rapid waste stabilization leading to a shorter post-closure period are certainly desirable and achievable.

In the interest of moving landfill technology one more step forward to replace the dry tombs, below are just a few broad concepts that can be adopted with minimal changes to currently accepted landfill design and operations practices.

### Apply for RD&D Project

First and foremost, the waste disposal industry should take advantage of the existing RD&D Rule as it currently stands, and consider the alternative design and operational concepts that will facilitate waste stabilization. The RD&D Rule is flexible and already allows for a wide variety of options including the introduction of leachate and liquids on alternative bottom liners as well as the introduction of other materials or special waste processing, to enhance the degradation of organic matter contained in the solid waste. The program requires technical justification and monitoring and is currently available for a period of up to 12 years.

It is therefore timely that EPA is proposing to extend the duration of an RD&D project from 12 to 21 years, which is a positive step forward and will allow landfills more time to develop and adopt operational and design changes that might facilitate waste stabilization. Whether through recirculation of leachate, stormwater runoff/run-on management, or by other means, RD&D is open-minded and has limited restrictions provided that the methods are well engineered, monitored, and the results are measured and evaluated over time. More facilities should take advantage of the RD&D rule to not simply to reduce their post-closure period, or enhance degradation, but to experiment with technologies that might add to the body of knowledge for other facilities to consider and apply at their sites.

### Let Some Leakage In (Without Taking a Bath)

As noted, Subtitle D rules were written to address concerns over the bathtub effect, which led to the requirement for a relatively impervious final cover. However, since the leachate collection system (LCS) must be designed and operated to maintain a maximum 30-centimeter hydraulic head over the liner under all conditions—including a fully open cell/no waste condition, through each active filling phase, at the time of final closure, and through the post-closure period—the probability of creating a bathtub seems to be relatively low. If the amount of leakage allowed to enter the waste can be reasonably estimated from available water balance models, and controlled and monitored effectively, allowing some leakage should pose limited risk, and positive measurable benefits, even if it is limited to the capacity to absorb the liquid before reaching field capacity.

Table 1 provides a theoretical guide to how much liquid can be added to sanitary waste (assuming different initial moisture contents) to achieve final moisture contents of 30, 40, and 50%. Other factors may also be considered in arriving at realistic values: the impact of daily cover soils on infiltration, type, and characteristics of the waste,

*Continued on S22*

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Table 1

| Initial Waste Moisture Content (% wet)*---- | 15 | 20 | 25 | 30 |
|---|---|---|---|---|
| Moisture Content Goal (% wet) | Max. Liquids Addition in Gallons/Ton | | | |
| 30 | 52 | 34 | 17 | 0 |
| 40** | 100 | 80 | 60 | 40 |
| 50 | 167 | 144 | 120 | 96 |

*Assume wet waste density = 1,200 pcy
**Approximate Field Capacity, F'c

including hydraulic conductivity, density, and organic content. There are numerous articles and case studies that provide such information.

Under this category, incorporating final cover systems that allow some amount of leakage, such as a soil-only cover, or an evapotranspiration (ET) cover, or even a hybrid cover that combines separate areas of FML and soil components should be considered, rather than the standard full-coverage geomembrane.

## Limited Leachate Recirculation

Even with the flexibilities provided for in Subtitle D and RD&D to allow recirculation, the number of facilities that practice recirculation successfully is rather limited; some facilities have ceased doing so due to operational challenges including odors, seeps, stability, and settlement. But that was then, this is now: with very recent challenges in managing leachate treatment and the significant costs associated with leachate disposal, there has been a renewed and significant interest nationwide in leachate evaporation and treatment technology to reduce disposal costs.

While leachate evaporation technology is still developing, why not reconsider recirculation as an option or complimentary approach, even if on a limited basis? At the very least, limited recirculation will reduce the amount of leachate needing treatment, should enhance gas generation and waste stabilization, and create airspace. The practice of spraying leachate directly on the working face still works, and allowing run-on to the waste (allowed under RD&D) and similar simple, straightforward concepts will not necessarily require significant design or operational changes.

## Delay Final Closure Capping

Even if a landfill is equipped with an FML composite bottom liner, an FML final cover does not practice recirculation, and is thus relegated to the future as a dry tomb, the simple process of delaying of the final capping for several years may still provide significant benefits. Considering that landfill settlement continues to occur many years beyond the time filling is completed (and is a surrogate measure of gas generation), allowing a more significant period of time between the end of filling and final capping than allowed for in Subtitle D, such as three to five years or more, seems very reasonable. This assumes that landfill gasses and odors can be suitably managed, which allows time for precipitation to enter the waste and for a landfill to settle, enhancing degradation and minimizing airspace loss from early capping.

To this end, the Pennsylvania Department of Environmental Protection (PADEP) had the forethought to adopt a rule in 2014 that allows facilities to overfill waste above permitted grades, allowing waste settlement to occur for up to five years before final cover placement. Known as the Settlement Accommodation Plan (SAP), the state places various restrictions on overfilling slope angle, depth of allowable waste overfill, and requires both a technical evaluation of settlement coupled with annual measurements to validate that the overfill is performing well.

At the end of the five-year period, waste that is still above permitted final grades must be removed at the owners cost. The SAP was born from the concerns of landfill operators losing valuable airspace from post-capping settlement, which cannot be recovered, accommodates the understanding that landfills settle over time, and also promotes a form of wet landfilling by allowing time for precipitation and runoff to enter the waste, thereby accelerating waste decomposition, gas generation, and settlement. It seems well worth the cost and effort for landfills in Pennsylvania to adopt a site-specific SAP. Why not other states, too?

## Closing

The waste industry, in general, knows more about how waste responds to liquids addition from a variety of experiences, both good and bad, over the past two decades; but challenges and unknowns remain. We also recognize the difficulties with managing leachate recirculation/bioreactor landfills, understand more fully the rates that landfill gas is generated, how gas can be collected most efficiently, and how landfills settle over time, both with and without recirculation.

Armed with this knowledge and the desire to control operational costs, reduce post-closure monitoring, and still protect the environment, surely there are ways to advance landfilling beyond the dry tomb technology that was born in the 1980s to a nationwide improvement in landfill designs and operations for the next generations. The only real question that remains is: are we willing to try?

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