Review and Update
Developing More Environmentally Protective
MSW Landfills

G. Fred Lee PhD, MSPH, PE, AAEES, FASCE
Anne J. Lee, PhD

G. Fred Lee Associates
El Macero, California 95618
www.gfredlee.com gfredlee33@gmail.com
June 2021

G. Fred Lee has served as an independent technical consultant to governmental agencies, commercial concerns, and public advocacy groups for assessing potential public health and environmental quality implications of municipal solid waste landfills, hazardous waste landfills, and Brownfield site evaluation and redevelopment for nearly six decades. For half of his career he also served on university graduate school faculties, conducting research and training graduate students in these and other areas.

This review serves to

- announce our recent update of our Technical Review report, "Flawed Technology of Subtitle D Landfilling of Municipal Solid Waste," (Lee and Jones-Lee, 2021 – http://www.gfredlee.com/SubtitleDFlawedTechnPap.pdf) that addresses
  - issues of landfill composition, pollution potential, and inevitable environmental pollution,
  - key deficiencies in landfilling regulations and implementation that threaten long-term public health and environmental quality, and
  - aspects of developing more protective municipal solid waste (MSW) landfills
- describe the evolution of attempts to improve the protection of public health and environmental quality from landfilled municipal solid waste, and
- summarize key aspects discussed in detail in our updated Technical Review report concerning deficiencies in the current Subtitle D regulations and implementation for providing protection of public health and environmental quality for as long as the landfilled wastes pose a threat and steps needed to improve protection.

Where We Have Been

Historically and still, the disposal of municipal solid waste has been conducted in the least-costly allowable manner. When Dr. G. Fred Lee was introduced to impacts of MSW disposal practices on environmental quality in an academic course on public health practice in 1953, the common practice was for urban areas to dispose of their solid wastes by simply dumping them on nearby low-value lands, which were frequently wetlands. Even at that time it was recognized that that practice was problematic. Such open "dumps" attracted flies, gulls and other birds, rodents and other vermin and emitted highly offensive odors that were often detected by residents a mile or more from them. Waste components, especially paper and similar light-weight materials, were carried off-site by the wind, and surface and ground water pollution occurred near the dumps.

In the late 1950s the American Society of Civil Engineers Sanitary Engineering Division published a report discussing public health and environmental impacts of MSW management practices (ASCE, 1959). That report also advanced the "sanitary landfill" concept that prescribed that each day a thin layer of soil be placed over the newly dumped waste in order to reduce the entry of birds and rodent into the wastes. While some states adopted the "sanitary landfill" approach for MSW management by the 1960s, the approach was not effective in mitigating most of the typical problems of the open dump including offsite odors, release of hazardous gaseous chemicals to the air that were a threat to human health, subsurface transport of methane that can cause fires/explosions in nearby structures, groundwater and surface water pollution by landfill leachate, and windblown paper and other waste components to nearby properties. Without the ability of "sanitary landfilling" practices to mitigate many of the real problems, with essentially no dump-owner-owned buffer lands between disposal areas and adjacent properties, and with increasing public awareness of the public health and environmental quality problems being caused by the practice, significant and justified "NIMBY" (not in my backyard) sentiment was generated and increasingly voiced.

In the early 1980s, the US EPA conceived and began developing regulations for "dry tomb" landfilling of MSW under Subtitle D of the Resource Conservation and Recovery Act (RCRA). The "dry tomb" concept was to bury wastes between plastic-sheeting and compacted soil/clay liners and covers to try to keep the wastes dry in order to try to retard the generation of leachate and gas in the landfill. Recognizing that the engineered containment systems would fail over time, the US EPA added to the regulations collection systems to try to intercept and remove leachate and gas that will inevitably develop in the landfill, and monitoring requirements to try to identify when the collection systems failed. It was not intended or envisioned that "dry tombs" would render hazardous and otherwise deleterious components in the buried wastes innocuous; rather the "dry tombs" would simply contain the wastes for as long as the liner/cover systems maintained their integrity and delay the evidence of problems.

As the Subtitle D regulations were being developed, considerable research was being undertaken on the properties of plastic sheeting liners and composite liners/covers of the type prescribed for "dry tomb" landfills, and other aspects of the overall approach (e.g., see Lee and Jones, 1984). It became well-documented by the late 1980s that the plastic-sheeting/flexible membrane liner (FML) and compacted clay liner systems being prescribed for "dry tomb" landfills had significant problems in actually preventing moisture from entering landfills through the covers and in reliably collecting leachate generated by landfilled wastes before it escaped the site. The US EPA (1988a, b) draft revisions of Subtitle D regulations even included statements acknowledging that single-composite liner/cover systems incorporated into the minimum design standards would eventually deteriorate and fail to prevent entrance of water into a closed landfill and the release of leachate to pollute groundwater. Despite that recognition, the "dry tomb" regulations were promulgated and passed by the US Congress (US EPA, 1991).

As those regulations were being finalized Dr. Lee was invited to present a Workshop discussing issues of long-term protection of public health and environmental quality from municipal solid waste management in Subtitle D "dry tomb" landfills at the National Water Well Association (NWWA) Outdoor Action Conference (Lee and Jones-Lee, 1991a). In that workshop and in numerous papers and reports that he developed over the following 30 years, he discussed

potential problems that municipal and industrial "non-hazardous" waste landfills represent to groundwater quality over the long term, problems with relying on plastic sheeting and clay liners and caps for long-term protection from the buried wastes, and areas in which many state and federal regulations covering landfilling and postclosure maintenance of landfills could be improved. Specific guidance was provided on approaches that water utilities and others should follow to protect groundwaters that are or could be used for domestic water supply purposes from impacts from landfilled wastes, and improvements needed in municipal solid waste management to protect public health, groundwater quality, and the environment for as long as the wastes represent a threat. One of the major driving forces for not requiring that MSW landfills be more reliably protective of public health and the environment for as long as the wastes would be a threat was the concern that such requirements would significantly increase the cost of MSW management beyond what the public would tolerate given that the additional costs would be passed on to the public and commercial interests that contribute wastes to the landfill. US lawmakers, through several administrations, did not want to face the public opposition associated with increasing the cost of household and industrial solid waste disposal.

Drs. Lee and Jones-Lee continued their research and publication on problems with "dry tomb" landfilling as practiced, developing more protective landfills, guidance for the evaluation of potential impacts of proposed landfills and related issues (e.g., Lee and Jones-Lee, 1991b; 2004; 2015; 2016). They continued to work with clients who were concerned about the real protections afforded by the "dry tomb" landfilling approach and how to improve them, and prepared technical guidance for regulatory agencies, landfill applicants, and the public to help them better evaluate and enhance the adequacy of proposed and existing landfills (Lee and Jones-Lee, 1997). That guidance remains applicable.

Out of their work they developed a Technical Review summary paper of these issues, with extensive references to the professional literature, including discussing many of the significant problems with the Subtitle D landfilling approach that can be expected to impede or prevent it from meeting its intent to protect public health and the environment for as long as the wastes in the landfill will be a threat, causing it to be a "Flawed Technology." As new issues, technical information, and insights have developed in the field, they have updated the original document, the most recent update being in 2021 (Lee and Jones-Lee, 2021).

Additional information on Drs. Lee and Jones-Lee's experience, expertise, and writings concerning evaluation and management of public health and environmental impacts of municipal solid waste management approaches is available on their website, http://www.gfredlee.com, at http://www.gfredlee.com/Landfill_Impacts.html.

Where We Are

Typically landfilling regulations state that

(a) the solid waste facility is not to pose a substantial endangerment to public health or safety or the environment, and
(b) the solid waste facility is not to cause an environmental nuisance.

Frequently in review of a proposed landfill, regulatory agency staff does not adequately or reliably evaluate the potential for the landfill as proposed to endanger public health, safety and

the environment, and to cause nuisance problems on adjacent properties for as long as the wastes will be a threat. It is typically presumed that the landfill will be "protective" as long as the minimum Subtitle D design standards have been met and, if objections or concerns are raised, additional design elements have been imposed to assuage the objections and criticisms. The process does not squarely and reliably acknowledge and address the real deficiencies in the approach that prevent reliable protection of public health and environmental quality for as long as the buried wastes pose a threat – which will be for as long as they remain buried in the facility.

The US EPA (2021) website discussion of municipal solid waste landfills and their regulation continues to provide the public with overstated and incomplete information about the public health and environmental quality threats posed by MSW and the protection that is being provided by Subtitle D regulations. For example, the US EPA (2021) discussion of MSW as "non-hazardous" waste does not convey the fact that that designation is an administrative designation and is not indicative of the absence of hazardous or deleterious effects from these wastes. Rather the distinct impression is that MSW is not hazardous, when in fact they clearly contain chemicals and materials that can be hazardous or otherwise deleterious in the environment and/or to human health and welfare. One could argue that it is precisely because they DO contain such hazardous and otherwise deleterious components that Subtitle D regulations were developed to try to manage them.

For additional examples, in describing the engineered components prescribed by Subtitle D, the US EPA (2021) conflates what is desired from Subtitle D design features and what the design features can realistically be expected to provide over the period during which the waste in the landfill will be a threat. The US EPA summarizes major aspects of Subtitle D landfills thus:

- *Location restrictions—ensure that landfills are built in suitable geological areas away from faults, wetlands, flood plains or other restricted areas.*
- *Composite liners requirements—include a flexible membrane (i.e., geo-membrane) overlaying two feet of compacted clay soil lining the bottom and sides of the landfill. They are used to protect groundwater and the underlying soil from leachate releases.*
- *Leachate collection and removal systems—sit on top of the composite liner and removes leachate from the landfill for treatment and disposal.*
- *Operating practices—include compacting and covering waste frequently with several inches of soil.*
- *These practices help reduce odor, control litter, insects, and rodents, and protect public health.*
- *Groundwater monitoring requirements—requires testing groundwater wells to determine whether waste materials have escaped from the landfill.*
- *Closure and post-closure care requirements—include covering landfills and providing long-term care of closed landfills.*
- *Corrective action provisions—control and clean up landfill releases and achieves groundwater protection standards.*
- *Financial assurance—provides funding for environmental protection during and after landfill closure (i.e., closure and post-closure care).*

In its "Diagram of a Properly Closed Landfill" the US EPA (2021) describes the components thus:

- *Wells and probes to detect leachate or methane leaks outside the landfill*
- *Leachate pumped up to storage tank for safe disposal*
- *Clay and plastic lining to prevent leaks, pipes collect leachate from the bottom of the landfill Garbage/Sand/Synthetic Liner/Sand/Clay/Subsoil*
- *Pipes collect explosive methane gas to use as a fuel to generate electricity*
- *When the landfill is full layers of soil and clay seal the trash*

The US EPA (2021) does not give the public that is consulting its website for understanding and guidance when faced with siting of a proposed or expanded landfill, useful information to understand, and even question landfill proponents about, the ability of a particular facility to protect public health and environmental quality. Rather it implies and states that following Subtitle D regulations will provide protection of public health and the environment.

There is no discussion of issues such as those addressed by Lee and Jones-Lee (2021) including

- the nature of MSW leachate and ways it threatens public health and environmental quality
- limitations to its investigation, monitoring, and maintenance
- known and predictable limitations of the engineered components and systems,
- the difficulty, if not impossibility, of routinely inspecting much less repairing many aspects of the engineered systems over the hundreds and more years during which the wastes will be a threat,
- the susceptibility of the engineered systems to deterioration and breach, and reliability of the systems to perform as intended, and their realistic functioning lifetimes,
- the prescribed 30-year post-closure monitoring and maintenance period for which funding is to be ensured is but an infinitesimal portion of the period over which the wastes will be a threat, either as they remain entombed or as they leak hazardous and otherwise deleterious components into the environment.

Thus even to this day, key problems with the Subtitle D landfilling approach that have long-been recognized and discussed (Lee and Jones-Lee, 2021) remain largely unaddressed in the management of existing, and the development of new, Subtitle D landfills, and in the US EPA's promotion and advocacy of its regulatory sufficiency.

- In addition to containing relatively innocuous but potentially nuisance components, MSW contains materials that can be hazardous or otherwise deleterious to public health and environmental quality.
- Untreated MSW buried in landfills has the potential to generate leachate that will pollute groundwater with hazardous and otherwise deleterious chemicals that are a threat to human health and the environment for thousands of years.
- These landfills also retain the potential to generate landfill gas that will contain hazardous and obnoxious chemicals for a long period of time well-beyond the current minimum 30-year funded postclosure period.
- The ability to forestall the development and release of leachate and gasses depends largely on the ability of the facility to exclude moisture and collect and remove leachate.

The better the facility is in keeping the buried waste dry, the longer the release of leachate and gas will be postponed.

- An initially efficient landfill may delay such emissions for decades – but not for as long as the wastes remain. The burial of the wastes does not render them innocuous or non-hazardous.

As discussed in detail in papers cited herein, specific deficiencies in the siting, design, operation, closure and postclosure care provisions for Subtitle D landfills include:

- The fact that regulators do not give MSW a "hazardous" designation does not mean that such materials are innocuous. MSW contains materials that are and can be hazardous or otherwise deleterious to public health and environmental quality.
- There is rarely a reliable mechanism for incorporating into monitoring programs what are heretofore-unknown, unrecognized, unmeasured, and/or unregulated chemicals that are continually coming to light.
- Single-composite landfill liners will eventually fail to prevent leachate pollution of groundwater.
- Prescribed landfill covers will eventually allow rainfall and snow melt to enter the landfilled wastes, which will generate leachate that will pollute groundwater.
- Cover and liner systems are, in general, not amenable to effective inspection and repair in all areas that can fail. Thus inevitable breaches and areas of deterioration go unrepaired and allow entrance of water and exit of leachate/gas.
- Groundwater monitoring systems prescribed for landfill monitoring have a low probability of detecting leachate-polluted groundwater before it leaves the landfill owner's property.
- Types of development allowed atop closed landfills can adversely affect the integrity of the landfill cover system and the ability to monitor and maintain the cover.
- The passage of time does not render buried wastes innocuous. They will remain a threat for as long as they remain buried.
- Postclosure funding typically incorporated cannot be relied upon for reliable and proper landfill monitoring and maintenance, and remediation of polluted groundwater for as long as the wastes in the landfill will be a threat.
- The 30-yr period of postclosure care typically required is only a fraction of the time during which a Subtitle D landfill poses a threat. Engineered systems may well perform without noted breach for several decades, only to exhibit failures after the postclosure care period.
- Landfill-owner-owned buffer lands between landfilled wastes and adjacent properties are inadequate to ensure that when releases occur in the future they cannot be reliably detected and remedied before nearby property owners/users are adversely affected by landfill releases, including
    - presence of hazardous or otherwise deleterious chemicals in water supply wells
    - odors, dust, vermin, and noise and lights from landfill activities,
    - decreased property values for owners of nearby properties.
- Since landfills tend to be sited in areas where there is least public opposition or least adverse impact on the politically powerful/influential, there is concern about the siting of MSW landfills in areas that may disproportionately adversely affect those not having strong influence or deep pockets to oppose them.

Countries throughout the world tend to follow the US EPA approaches for developing MSW landfills increasing the reach of these deficiencies.

Developing Protective Landfills

Lee (2013) discussed issues of developing more reliably protective landfills based on his experience reviewing existing and proposed landfills at about 100 locations over about 60 years. The following discussion is from that paper.

The incorporation of a properly constructed double-composite liner with a leak detection layer between the two liners would provide more reliable early detection of liner breaches, before groundwater pollution occurs. When leachate is found in the leak detection layer, repairs would need to be made in the landfill cover to stop the penetration of water through the cover that can generate leachate. Rather than trying to rely on groundwater monitoring wells spaced a hundred or more feet apart at the point of compliance for groundwater monitoring to signal cover and liner breach (as is typically the case under minimum Subtitle D requirements), the failure of the upper composite liner would be detected by the presence of leachate in the leak detection layer, before groundwater is polluted. This approach, however, requires that adequate postclosure funding be available for landfill monitoring and maintenance for as long as the wastes in the landfill will be a threat, i.e., as long as they could generate leachate. To prevent crushed plastic bags in the waste from hiding wastes from moisture till the plastic bags decompose, the MSW would need to be shredded prior to landfilling. While such provisions could be readily implementable, their inclusion would increase the cost of MSW disposal several fold; those costs should be borne by those who generate the wastes that are disposed of in the landfill.

Also key to developing a protective landfill is the maintenance of adequate landfill-owner-owned buffer lands between waste processing/disposal areas and adjacent property lines. While Subtitle D and many other associated regulations require a few feet of buffer land, typically about 1 to 2 miles of buffer land owned by the landfill owner is necessary for the dissipation of odorous releases to prevent trespass of waste-derived chemicals onto adjacent property. As discussed in our "Flawed Technology" review cited above, landfill odors not only are highly noxious but also pose a health threat. Typically landfill proponents try to minimize the amount of landfill-owner-owned buffer land. They also tend to inflate the appearance of land buffering capacity offered by the landfill by focusing attention on distance between the waste deposition areas and the nearest exiting home, rather than between the waste deposition areas and the nearest adjoining property line. Their approach uses adjacent property for the dissipation of odors and other releases from the landfill, and thus uses others' property to expand the landfill "buffer land." Such appropriation of others' land reduces the value of adjacent property and contributes to justified NIMBY sentiment. The owner of property adjacent to a landfill should be able to use his/her property up to the property line without impact by releases from the landfill. All buffer lands should be on property owned by the landfill owner, and enforcement of landfill odor controls should be implemented at the adjacent property line.

Lee has pondered in writings on controlling landfill impacts on nearby properties potential advantage of siting MSW landfills not in "remote" areas at great distance from the locations in which the wastes are generated but rather right in the residential areas where they are generated.

Adopting such an approach could provide greater incentive to ensure that the operation of the landfill would be protective of all of those within the sphere of influence of the landfill.

The ultimate failure of single and double composite lined landfills as developed today lead to pollution of groundwater by landfill leachate could be largely controlled by required all new and expanded landfills to be double composite liners in which the lower composite liner is a pan lysimeter to detect when the upper compost liner fails to collect the leachate generated in the landfill and lead to leachate pollution of the leak detection system between the two composite liners.

Developing Residential Properties on Old Landfills

In urbanized areas where there is a shortage of land for residential housing there is pressure to force the development of residential housing on lands that are not suitable for a variety of reasons such as old landfills and near industrial activities. Such redevelopment visions often come with open-space and water features for development ambience and appeal. Investigation and "remediation" of the landfill area in advance of redevelopment can be minimal, such as placing a shallow layer of "clean soil" atop the buried wastes, and reliable long-term (ad infinitum) monitoring is often lacking. This practice is concerning from the point of view not only of monitoring, maintenance, and inevitable remediation of the landfill, but also of maintaining the integrity of the engineered systems of the landfill and of the impacts on public health and environmental quality of the hazardous and otherwise deleterious components of the landfill.

Questions or comments should be directed to G. Fred Lee at gfredlee33@gmail.com

References

ASCE, "Sanitary Landfill," Report Committee on Sanitary Landfill Practice of the Sanitary Engineering Division of the American Society of Civil Engineers, New York, NY (1959).

Lee, G. F., "Developing Protective Landfills," Report of G. Fred Lee & Associates, El Macero, CA, January 19 (2013).
https://www.gfredlee.com/Landfills/Sum_Developing_Protective_Landfills.pdf

Lee, G. F., and Jones, R.A., "Is Hazardous Waste Disposal in Clay Vaults Safe?" Journ. American Water Works Association 76:66-73 (1984).
https://www.gfredlee.com/HazChemSites/ClayVault.pdf

Lee, G. F. and Jones, R. A., "Municipal Solid Waste Management: Long-Term Public Health and Environmental Protection," Workshop Lecture, National Water Well Association National Outdoor Conference, Las Vegas, NV, May (1991a).
https://www.gfredlee.com/Landfills/MSWMANAGT.pdf

Lee, G. F. and Jones, R. A., "Ability of 'Dry Tomb' Landfills to Provide Long-Term Protection of Groundwater Quality: The Picture Is Bleak," Response to the Letter of the Editor, ISCHIA News, September (1991b).
https://www.gfredlee.com/Landfills/DryTombProtect_Bleak.pdf

Lee, G. F. and Jones-Lee, A., "Questions that Regulatory Agencies, Staff, Boards and Landfill Applicants and Their Consultants Should Answer About a Proposed Subtitle D Landfill or landfill Expansion," Report G. Fred Lee & Associates, El Macero, CA (1997). https://www.gfredlee.com/Landfills/subdques.pdf

Lee, G. F., and Jones-Lee, A., "Overview of Subtitle D Landfill Design, Operation, Closure and Postclosure Care Relative to Providing Public Health and Environmental Protection for as Long as the Wastes in the Landfill Will Be a Threat," Report of G. Fred Lee & Associates, El Macero, CA (2004). https://www.gfredlee.com/Landfills/LFoverviewMSW.pdf

Lee, G. F., and Jones-Lee, A., "Guidance on the Evaluation of Potential Impacts of a Proposed Landfill," Report of G. Fred Lee & Associates, El Macero, CA (2015). https://www.gfredlee.com/Landfills/EvaluationImpactLF.pdf

Lee, G. F., and Jones-Lee, A., "Issues of Long-Term Protection: Landfilling of Hazardous Wastes and Municipal Solid Wastes," Report of G. Fred Lee & Associates, El Macero, CA, February (2016). https://www.gfredlee.com/Landfills/Comments_RCRA_HWLF.pdf

Lee, G. F. and Jones-Lee, A., "Flawed Technology of Subtitle D Landfilling of Municipal Solid Waste," Report of G. Fred Lee & Associates, El Macero, CA, December (2004). Last updated January (2021) https://www.gfredlee.com/Landfills/SubtitleDFlawedTechnPap.pdf

US EPA, "Solid Waste Disposal Facility Criteria; Proposed Rule," Federal Register 53(168):33314-33422, 40 CFR Parts 257 and 258, US Environmental Protection Agency, Washington, D.C., August 30 (1988a).

US EPA, "Criteria for Municipal Solid Waste Landfills," US Environmental Protection Agency, Washington, D.C., July (1988b).

US EPA, "Solid Waste Disposal Facility Criteria: Final Rule, Part II," Federal Register, 40 CFR Parts 257 and 258, US EPA, Washington, D.C., October 9 (1991).

US EPA, "Municipal Solid Waste Landfills," as viewed June 12 (2021). https://www.epa.gov/landfills/municipal-solid-waste-landfills