SOME ESSENTIAL FACTS ABOUT LANDFILL GAS EMISSIONS

Peter Anderson

Controversy has swirled around the effectiveness of the piping systems used to collect landfill gas, for there currently is no verifiable method to measure emissions.[1] In a recent article,[2] Amy Van Koken Banister and Pat Sullivan argued that critics of the landfill industry's impressive claims – that gas capture "approach[es] 100%" – are engaged in unsupported rhetoric.[3] However, in view of the thousands of odor complaints against landfills,[4] the industry representations appear on their face to be hyperbole, even before examining the technical details that follow.

IPCC Report

Far from being debunked, the major concern raised by independent experts mirrors the analysis followed by the Intergovernmental Panel on Climate Change (IPCC) when it finalized consideration of the peer review comments on its Fourth Assessment Report (FAR). Its conclusions provided the basis to recognize that a landfill's capacity to collect gas is congenitally poor, in contrast to the industry's modeling that only hold otherwise by focusing on the wrong metric.[5]

The draft waste chapter in FAR was largely written by a US landfill consultant, Dr. Jean Bogner. In reliance on the same study by Kurt Spokas that Banister and Sullivan cite,[6] and which she coauthored, her draft claimed capture rates greater than 90%.[7]

However, during that review of the draft chapter, a Dutch engineer, Hans Oonk, submitted seminal comments that questioned Spokas' reasoning. Oonk explained that Spokas' attempt failed to recognize the relationship between gas generation and capture over the entire period that gas is generated, which he referred to as the "integrated rate."[8]

Underlying Facts

To understand Oonk's point, four noncontroversial facts need to be considered:

- ✔ High moisture levels, only intermittently present, are a prerequisite for gas generation.[9]
- ✔ A final cover, only installed for the middle of a landfill's life, is necessary for gas collection to work properly.[10]
- ✔ Gas generation tapers off after the site is capped.[11]
- ✔ Gas capture is largely nonexistent when there is sufficient moisture to generate gas.[12]

The Oonk Paradox

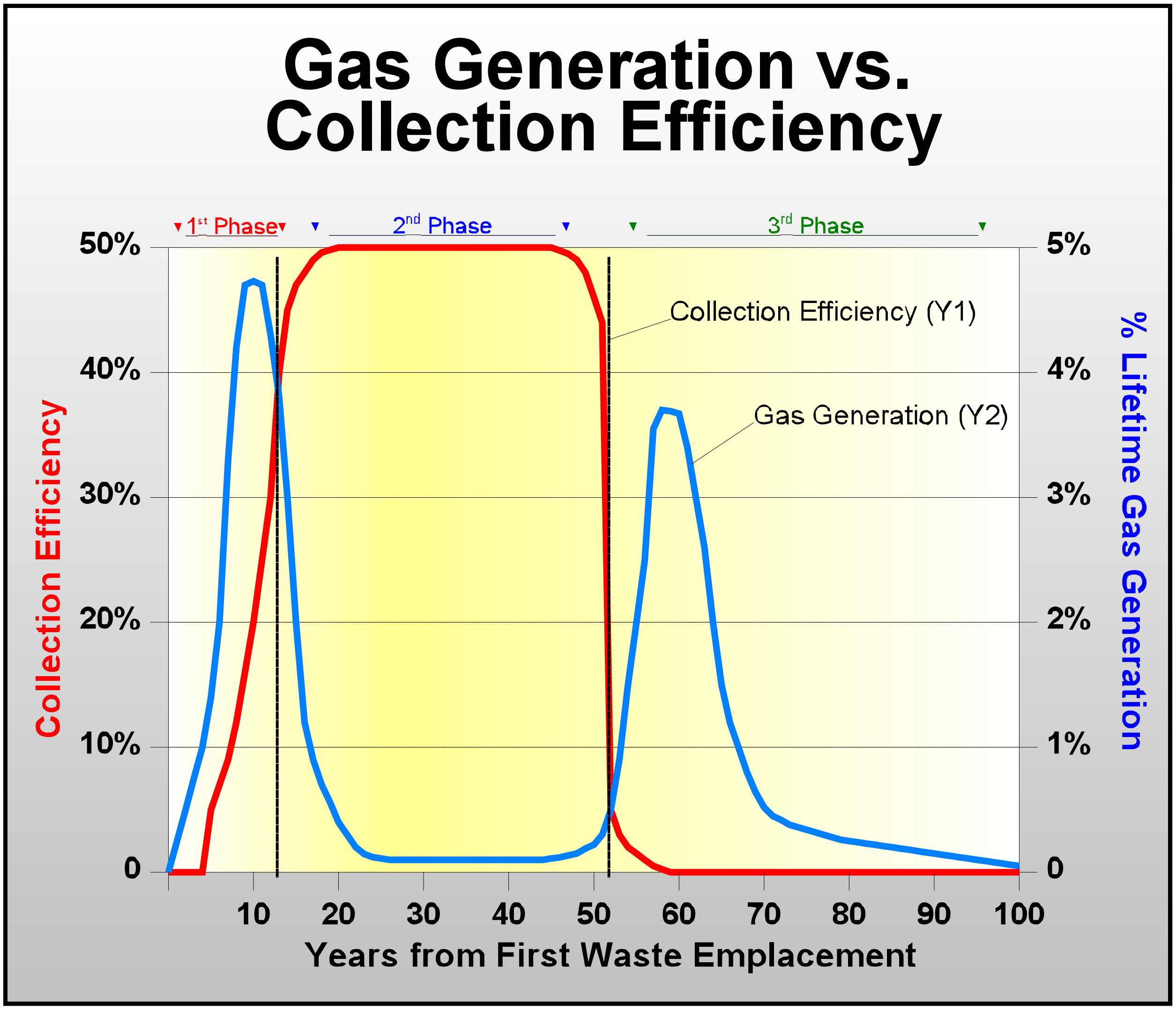
From this, Oonk presented a paradox to the IPCC. Gas collection only works properly when the site is, and for as long as it remains, sealed. But, this middle period of a landfill's life, which is the time that Spokas focused on, is also when relatively little gas is generated due to the absence of critical moisture.[13] When gas is generated – which is before and after that dormant middle period – there is either no gas collection or poorly performing capture systems.

IPCC Adopts Oonk Interpretation

In the final version of the FAR, the IPCC continued to state that the best systems could achieve more than 90% collection efficiency during the time a landfill is sealed. But, the Panel also inserted essential qualifiers to that statement. First, it pointed out the obvious fact that not all landfills perform optimally and others “may have less efficient or are only partial gas extraction systems.” Second, adopting Oonk, it added “there are fugitive emissions from landfilled waste prior to and after the implementation of active gas extraction.” Therefore, the IPCC concluded, “estimates of ‘lifetime’ recovery efficiencies may be as low as 20%.”[14]

Double Dutch Curves

The chart below, which reassembles “Double Dutch” jump ropes, illustrates the Oonk paradox, albeit without actual field data (since that does not exist).



SOURCE: Center for a Competitive Waste Industry

The chart is divided vertically into the three phases of a landfill's life –

① Before gas capture is functional;
② The middle period when it is; and
③ After the collection systems are shut down.

The blue line shows the approximate proportion of total lifetime gas that would be generated in each year. The red line suggests how gas collection performance varies over that same period.[15] Key is the fact that most gas generation (the area under the blue curve) tends to occur at a time when collection efficiency (the red curve) is zero or quite low, and *vice versa*.[16] Thus, there is no need to debate collection efficiency in the Second Phase, because so little gas is generated then.

To help explain the poor gas performance in the First and Third Phases, consider –

First Phase

Gas collection is absent or not fully functional in the First Phase of a landfill's life (generally up to about the first 10, or more, years until the entire site is capped). While gas starts being generated a few weeks after garbage is buried,[17] the collection systems are not required to be installed for five years.[18] But, merely installing gas wells then does not, by itself, mean the system will work as designed. In reality, operational practices have fundamentally changed in the last decade, driving up fugitive emissions.

The 1991 federal landfill rules were predicated on *dry tomb* precepts. They required liners and covers, along with liquids and gas removal systems, to keep the site dry and biologically inactive for as long as possible in order to minimize mobilization of pollutants into the atmosphere and groundwater.[19]

However, by the end of the 1990s, the landfill industry determined to reverse course by deliberately boosting moisture levels. These *wet cell* practices include recirculating leachate and delaying installation of the final cover to allow more time for rain to infiltrate the waste mass.

By augmenting moisture, the operators sought to capture the financial and operational benefits from accelerating decomposition.[20] Two or more times the air space could be recovered from greater subsidence and resold. Also, leachate treatment costs could be lowered.[21]

There is no real controversy that these wet cell practices also shift gas generation from the future to the present, as well as increase the concentration of methane in that gas.[22] That means not only is near-term methane generation being increased, but so is, cumulatively, the aggregate methane produced over a landfill's biologically active life. Together, methane generation in the next 10-20 years, is three times what would be the case had the shift to wet cell practices not occurred.[23]

Widely acknowledged, also, is the fact that these changes significantly degrade near-term collection efficiency.[24] Thus, much more methane is produced in the short-term, and more of that escapes, at a time when we confront irreversible climate tipping points.[25] While there are no field measurements of the impact on gas capture, the inference from EPA studies suggests collection efficiency in wet cells is 45% less than in a dry landfill. In consequence, in the near-term 10× more methane will be released, with 250× the warming impact, than from traditional landfills.[26] EPA states that it "does not anticipate that [dry tomb landfills] will be in the majority" in the future.[27]

Third Phase

The Third Phase points to the impact on gas emissions in the final chapter of a landfill's life, after a 30-year period of maintenance ends following closure.

Once the buried trash reaches final grade, the landfill is to be sealed with some final cover to minimize infiltration of precipitation and keep the site biologically inactive.[28] Then, EPA's rules designate the 30 years that follow as the postclosure period.[29] During that time, the owner is also to provide some financial assurances for, and to perform the work involved in, maintaining the site.[30] But, after postclosure ends, those obligations generally cease. This implies care will eventually taper off.[31]

Without maintenance, the barriers will deteriorate and, EPA acknowledges, "ultimately fail,"[32] permitting rainfall to re-enter the site. This will reignite a second wave of gas generation,[33] even while the site remains a threat to the environment.[34]

Finally, before that second wave of gas commences, at some time during the 30-year postclosure period, the gas system will have been removed from service.[35] Therefore, those second wave gases will escape uncontrolled.

Banister and Sullivan argue that there will be no emissions following closure because, during "late phases of a landfill's lifetime, LFG generation is at its lowest"; even if there are any remaining organics left to decompose, there "is no evidence of landfill covers failing in United States in post-closure to any substantial degree"; and, even if there were failures, "that methane [might be] oxidized in the landfill cover."[36] But, these claims conflict with observations and reasonable projections.

In fact, the first order decay model they use to conclude there is no late-life gas fails to account for the fact that moisture, necessary for early gas generation, is inadequate to decompose more than a fraction of the freshly buried organics.[37] Test data demonstrates that leachate flows through narrow channels, and does not come in contact with most of the wastes while the site is still open, which leaves more gas for later.[38] Also, EPA's own Inspector General has found that many caps fail even before maintenance ends, and most agencies that addressed this issue anticipate future cover failures.[39] As regards the claimed oxidation effects, in modern landfills gas escapes in high fluxes through tears in geomembranes, which overwhelms biocovers.[40]

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Unfortunately, the spacial and temporal challenges at today's megafills have defeated efforts to craft field measurements or models that could inform us with an accurate point estimate of how effective typical landfill gas collection actually is. But, the life-cycle framework incorporated into the IPCC's Fourth Assessment tells us more than enough to know that only a trivial fraction is captured. ❐

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END NOTES

Due to space constraints in the print version of MSW Management, the END NOTES to the text accompany the magazine's on-line edition of the article, at
http://www.mswmanagement.com/january-february-2011/lfg-response.aspx

[1] See, e.g., Memorandum to Brian Guzzone (Environmental Protection Agency), from Chad Leatherwood (Eastern Research Group, Inc.), dated November 18, 2002, re: Review of Available Data and Industry Contacts Regarding Landfill Gas Collection Efficiency, at p. 2:

> "Overall, there is minimal data on LFG collection system efficiency. Based on discussions with several industry contacts, this shortage of available collection efficiency data is due to difficulty in documenting uncontrolled LFG emissions. Accurately measuring uncontrolled LFG emissions is troublesome due to several reasons. Emissions from landfills do not come from a single point, or even a specific area. The fact that LFG can migrate horizontally, as well as vertically, within a landfill before entering the atmosphere results in uncontrolled emissions emanating from almost anywhere above a landfill cell. Given the size of municipal solid waste landfills, attempting to accurately measure emission rates from the entire landfill surface is complex. LFG generation rates are variable. Due to the heterogeneous nature of municipal solid waste, temperature variations with a landfill, variation in rainfall levels, and ongoing placement of waste in landfills, emission levels vary spatially across the surface of the landfill as well as temporarily. Thus, short-term measurements of uncontrolled LFG emissions only provide a snapshot of a changing emission dynamic."

Similarly, in EPA's emission factors for landfills:

> "Evaluating uncontrolled emissions from landfills can be a challenge. This is due to the changing nature of landfills, scale and complexity of the site, topography, and spacial and temporal variability in emissions."

EPA, *AP-42 Compilation of Air Pollutant Emission Factors*, Chapter 2.4 Municipal Solid Waste Landfills (Revised) (October 2008), at p. 2.4-4.

Also, the IPCC has stated:

> "Monitoring and measuring CH_4 emissions at the SWDS's surface is a demanding task, and there are no generally agreed or standardised methods available for routine or long-term monitoring because the emissions come from a large area and vary throughout the year."

> "Surface landfill gas (LFG) emissions are highly variable both spatially and temporally. Emissions vary on a daily basis as a result of changes in air-pressure and due to rainfall which affects the permeability of the top-layer. On top of that there is a seasonal variation in emissions as a result of reduced oxidation in winter. Additionally, emissions vary over the sections of the SWDS, due to differences in waste amounts, age and composition. Due to the high horizontal permeability, compared to vertical permeability, the slopes of a SWDS generally have higher emissions than the upper surface. On a more local scale, emissions are highly variable due to regions of reduced permeability in the subsurface and due to cracks in the surface. As a result, emissions at locations a few metres away from each other can vary over a factor 1000."

IPCC, *Guidelines for National Greenhouse Gas Inventories*, Solid Waste Chapter 3 (2006), at pp. 3.21 and 3.22.

Hans Oonk concluded:

> "In the end, modeled methane emissions are highly uncertain, due to a propagation of errors, which is highly unfavorable."

Hans Oonk, Literature Review: Methane from Landfills - Methods of Quantify Methane Generation, Oxidation and Emissions (Sustainable Landfill Foundation, April 2010), at p. 6.

We agree with this recitation of the spacial challenges that have precluded reliable measurement of fugitive emissions, to which we would add, as Oonk and the IPCC have described, the concomitant temporal challenges involved. For most landfill gas is generated prior to and after the time examined in the current studies.

[2] Amy Van Koken Banister and Pat Sullivan, "LFG Collection Efficiency: Debunking the Rhetoric," *MSW Management*, Elements 2011 (June 2010), at p. 26.

[3] Banister, *op. cit.*, at 26 and 28.

[4] Tim O'Donnell, "What's That Smell?," *Waste Age* (December 2006). Detection of methane has historically been used as a precursor of the odor problems that lead neighbors to complain. In the early 1980s, research by the California's South Coast Air Management District found an excess of 500 ppm of methane at the landfill surface tended to be followed by odor complaints. Linda Basillo, *et al.*, *Staff Report on Proposed Rule 1150.1: Control of Gaseous Emissions from Active Landfills* (South Coast Air Quality Management District, February 19, 1985). Thus, if there are persistent, recurring and widely perceived odor problems, that suggests there also are significant releases of methane (which were it by itself would be odorless). Pervasive odor complaints appear to be inconsistent with Banister and Sullivan's assumptions of high capture rates.

The headlines from recent news accounts of these complaints, including at the sites of the largest national firms which profess near perfect gas controls, illuminate the extent to which Banister and Sullivan's narrative seems to deviate rather significantly from reality.

> "Odor leaves 'bad taste,'" "Odor complaints from Millersville landfill on rise: Neighbors say they've had nausea and headaches from gas smells," "Waste Management to pay fine for Mass. landfill odor," "Lorain landfill stench may end with legal settlement with Ohio attorney general," "Imperial Landfill odors still a problem," "Janesville officials working to stop landfill stench," "Grayslake landfill works to quell odor complaints," "Rumpke-owned Ohio landfill to pay air pollution fine," "Landfill opts to pay hefty fine for odors," "Something's rotten in city of Suffolk," "Hinds landfill told to find source of foul odor," "No surprise: landfills stink," "Lee County Landfill stinks," "Landfill odor complaints return, "Mallard Ridge tries not to look or smell like a landfill," "Landfill pollution, odor concern Lee residents," "Oh that smell...and it may only get worse in West Orange Plans to expand a landfill have neighbors in the Lake Avalon rural settlement crying foul," "Opponents scuffle, but state says landfill stink could be nearing an end," "landfill odor complaints return," "Landfill operator to pay $1M, control odor," "Smells linger at Stark landfill: State, federal regulators to test in Pike Township for source of foul odors," "Landfill odor riles Newburyport residents," "Landfill growth worries residents: Santee neighbors complain of odors," "Landfill expansion plans, odors trouble neighbors," and "Hoping to clear the air: Parents, educators at odds over emissions near school," and "New Jersey is Covering Its Landfill Stench in True Jersey Style: With Cheap Perfume."

Possibly, Banister and Sullivan meant to represent that only the best landfills exhibit the claimed near 100% performance levels. If so, and regardless of whether it is true, that point would be irrelevant to real world concerns about greenhouse gas emissions. For EPA has concluded, and logic compels, "[t]o be useful for estimating methane emissions, the landfills in the data set must be *representative* of landfills generally in the U.S." EPA, *Anthropogenic Methane Emissions in the United States* (EPA 430-R-93-003, 1993), at p. 4-12 (emphasis added), even though the agency has honored its precept more in the breach. Hence, whatever the best landfills actually do achieve has no bearing on the questions before us.

Alternatively, they may have meant to qualify their claim to exclude the time a landfill is open. But, as discussed in the text, excluding that period (and after the cover fails decades hence) is precisely when most of the gas is generated.

Further, notably these complaints about noxious landfill odors continued even after the industry developed an array of low-cost expedients to mask, but not eliminate, them, such as, on hot and humid days, using fans, misting odor suppressants and perfumes, along with wider buffer zones around the landfill and buy-outs of obstreperous neighbors. Chaundra Fierson, "Get Rid of da Funk," *Waste Age* (January 2000); Marsha DeClue, "That's Not Roses You Smell," *MSW Management* (January/February 2009), Lynn Merrill, "Keeping a Lid on Odor," *Waste Age* (April 1999). None of these strategies, incidentally, reduce actual emissions into the atmosphere. Yet, regulators often appear to be focused on misting to reduce the odors, without acting to address the actual emissions of GHGs and hazardous air pollutants (HAP), which reflects the fact that the regulatory landfill air program is primarily about odor management, not GHG reductions. Thus, as an example, after odor complaints against the Waste Management King George bioreactor landfill, the Department of Environmental Quality was reported to have recommended the operator purchase an "odor abatement system, which will spray a mist to neutralize odors". Cathy Dyson, "Landfill leaching not a problem," *Free Lance-Star* (September 22, 2010).

Of further concern, the operational preconditions at landfills, which are necessary to be able to control odors, may actually be deteriorating. The recommended list for best management practices to control odor from the leading trade association does include important modifications to current practices, such as better and earlier gas collection systems, along with smaller exposed working faces. National Solid Waste Association of North America (NSWMA), *Managing Solid Waste Facilities to Prevent Odor*, (Monograph, 2004). But, the continued growth of wet cell practices found by EPA in the field, Response to Comments (Subpart HH), Mandatory Greenhouse Gas Reporting Rule, 74 FED. REG. 209 (October 30, 2009), at p. 72, is widely known to increase uncontrolled odors. For accelerating decomposition entails larger and wetter working faces kept open longer, and sometimes accompanied by the addition of malodorous sewage sludge, all of which appears was intended to have been discouraged by NSWMA's best practices guidelines. These factors suggest that the economic boost to short-term profits, which animated the shift from dry to wet cell landfills, is presumably greater than the costs that follow from irate neighbors and occasional small fines from regulators.

Thus, the economic drivers in the real world, in contrast to idealized and subjective modeling, suggest that the problem in the real world may not only be too intractable to resolve, but also, to even paper over. For the type of changes needed to control emissions during the challenging times while the site is still open – as largely laid out in the industry's own best practices manual – would require a fundamental restructuring of the landfill industry. Those changes, often discussed in the literature and conferences, include at a minimum, such things as limiting the height of landfills to less than 100 feet (compared to more than 300 feet at today's megafills) so each cell would be able to be closed more quickly; preprocessing to homogenize the incoming wastes; reducing in-situ compaction from as much as 2,000 lbs/yd^3 to <1,000 lbs/yd^3; reverting from wet cell to dry tomb principles; returning to 6" of dirt for the daily cover from tarps that are removed much of the time; and laying horizontal trenches or drain pipe with each day's lift solely to extract gas, not primarily to add liquids.

But, these changes would tend to shift the industry's economics from being the low cost toward being the high cost producer relative to the alternative competing means of managing organic discards. That is to say, proper gas management practices would tend to economically drive a market shift away from landfilling to diversion as the least cost option. The prospect of investors selling of their stock could work as a powerful incentive for the landfill industry to vigorously resist those changes that are essential to reduce emissions in the absence of an rigorous regulatory environment, which, as discussed next, does not exist.

Worse still for climate change in particular, at standard pressure, methane is odorless and colorless, George Tchobanoglous, *Integrated Solid Waste Management: Engineering Principles and Management Issues* (McGraw-Hill, 1993), at p. 382, as well as practically impossible for its fugitive emissions to be measured, see ENDNOTE 1. The evidence suggests that even vociferous complaints by neighbors and compliance orders by regulators are insufficient to convince landfill operators to do what is required to reduce the type of emissions that are immediately evident and contentious. Thus, there does not appear any clear basis to anticipate that landfill operators will incur the major financial losses needed to substantively minimize methane releases, which are effectively invisible, at the expense of a favorable earnings report at the end of the next quarter, and the industry's competitive position and stock valuation at year's end.

If the underlying economics makes it exceedingly unlikely that landfill owners will voluntarily make the fundamental changes necessary to reduce methane emissions, the final question is whether the current regulatory structures can be utilized to do so.

Unfortunately, landfills are not subject to any meaningful regulation that might enforce the societal desired corporate behavior on the operator at a substantially greater cost to company. Nominally, there are regulations, but they do not require more than token compliance, and even that by only the largest facilities.

The New Source Performance Standards (NSPS) for landfill emissions under §111 of the Clean Air Amendments of 1990, promulgated in 1996, 40 CFR Part 60 WWW, were limited to only the largest landfills. Exempted from the regulations were 95% of the landfills and 61% of the methane emitted by landfills. 61 FEDERAL REGISTER 9914 and 9916 (March 12, 1996). This major exemption may be compared to the European regulations that apply to all landfills.

Also, the operators at the mega-sized landfills were given "flexibility" to install any type and configuration of a collection system that they preferred, only so long as it "collects gas at a *sufficient* rate," 40 C.F.R. §60.752(b)(2)(ii)(A)(*3*), while "*sufficient*" remained undefined, as did the other references to "*adequate* capacity," 40 C.F.R.§60.752(b)(2)(ii)(A)(*1*), "*sufficient* [well] density," 40 C.F.R.§60.759(a)(intro.)(1) and (2); §60.759(a)(1) and (2); §60.751 and 40 C.F.R. §60.755(a)(1)(iii)(2), and "*sufficient* extraction rate," 40 C.F.R. §60.752(b)(2)(ii)(A)(*2*); §60.751and §60.751 (emphases added). This contrasted with the original proposed rule, which was prior to the President's declaration of an "end to big government," that was prescriptive and applied to almost twice as many landfills. As EPA stated, "the proposed design specifications were removed from the final regulations [to] allow sources to design their own collection systems [and] to provide flexibility and encourage technological innovation." 61 FEDERAL REGISTER 9911 (March 12, 1996).

Since the rule was published, not only have wet cell practices been allowed without any formal review of the obvious increase in fugitive methane. Also, the typical landfill is said to have widened the space between landfills from about 150 feet in the 1990s to almost 350 feet today as improvements in misting techniques have helped mask the odor problems that follow poorer coverage. This also occurred without any apparent formal comment or objection from EPA, even though the self-apparent consequence is to significantly decrease the collection system's capacity to extract gas from the more distant surrounding gas field boundary and increase the frequency the system will short circuit.

The rule did include a so-called "sniff test" of methane concentrations at the surface, taken about 100 feet apart, four times a year, 40 C.F.R. §60.753(d) and §60.755(c), which some argue is a performance test. But the 500 ppm level is arbitrary in that it bears no known relationship to any specific level of collection efficiency; the testing protocol, which depends upon diffused emissions, is inapplicable to the standard composite or thick clay cover in which gas escapes in a few places in high fluxes; and the protocols are quite easy to deceive by timing sampling to periods of inherently low emissions and deliberately avoiding sampling the precise locations where leaks are most likely.

Finally, over the past three decades, regulatory institutions have been steadily weakened and staffing reduced, as was recently disclosed in the aftermath of the BP oil spill, e.g. Siobhan Hughs, "Chief Concedes Drilling Regulator Relied on Industry," *Wall Street Journal* (August 12, 2010). This suggests that, without more, even reforming the current system with stronger rules might not be sufficient to force landfills to make the necessary changes.

For technical background on the subject, landfill odors are extremely noxious and instantly recognizable, and are most frequent on hot, humid days. While the rotten egg odor of hydrogen sulfide is present as a byproduct of anaerobic decomposition of garbage, as well as construction and demolition debris, the chemical compound that is most associated with landfills' distinctive aroma is methyl mercaptan from the reduction of sulfides. Tchobanoglous, *op. cit.*, at p. 89. These compounds that cause the distinctive odors have been associated with mucous membrane irritation, respiratory irritation, nausea and stress. Agency for Toxic Substances and Disease Registry, *Landfill Gas Primer: An Overview of Environmental Health Professionals*, at p. 10 (2010).

[5] As explained in the text that follows, even if the Spokas methodology correctly described the middle period he focused on – which, as is suggested in this note, he does not – the effect on *lifetime* gas performance would be negligible for the reason that Oonk states:

> "More than 90% can be recovered in cells with final cover. However this is of little importance for the effectivity of LFG-recovery as a measure to reduce methane. A final cover is [installed] when there is no risk of settlements anymore and thus when biological activity has largely disappeared. If you catch 90% of the last remaining 10%, you are talking only about 9% of the total methane emission."Hans Oonk, Expert Review of First Order Draft of Waste Chapter to IPCC, Fourth Assessment Report, at Comment 10-37.

In any event, for the following reasons the Spokas methodology also fails to model gas capture correctly during that largely irrelevant middle phase of a landfill's life, when the site is covered and little gas is generated.

Best Case. First, there is the question of whether the Spokas and other such studies define performance (here in the middle period) as what the *best* landfills achieve, or do they define performance based upon the *typical* landfill. Spokas does not specify how he selected his very small sample of three out of approximately 6,000 French landfills. However, there has been a pattern to these types of studies in which attention is focused on only the best run facilities. For example, the major study underlying the EPA's capture rate assumptions is by R.L. Peer. His data set was drawn from 21 also non-randomly selected landfill sites, which is less than 1% of the total population. Landfills in the sample were reported to have been selected on the basis that the sites were thought to be "optimized" or landfill operators "appeared to be trying to optimize methane recovery." R. L. Peer, et al., *A comparison of methods for estimating global methane emissions from landfills*, 26 CHEMOSPHERE 387 (1993). Putting aside the question of whether mass balance methodologies are applicable to landfills, the Agency's use of an acknowledged best-case analysis is ironic in view of the fact that EPA had previously determined that: "[t]o be useful for estimating methane emissions, the landfills in the data set *must* be representative of landfills generally in the U.S." EPA, *Anthropogenic Methane Emissions in the United States* (EPA 430-R-93-003, 1993), at p. 4-12(emphasis added).

Model Dependent. Second, of course there is the failure to consider the entire time period when gas is generated, including the times when there is little or no gas collection, as well as the distortions from confining consideration to the best systems. But, beyond that, the attempts by Spokas and other similar studies to provide objective data on gas collection efficiency suffers from their dependence on modeling, in lieu of observations, whose premise, structure and input values are not correct.

Their methodology for estimating capture rates relies on a mass balance equation (ignoring for a moment variables claimed for oxidation, sequestration and migration, which are peripheral to the model's validity), is as shown in EQUATION 1:

EQ. 1 • ***Gas Released = Gas Generated - Gas Captured***

Unfortunately, two of the factors – Gas Released and Gas Generated – are unknown, which makes it impossible to solve the equation. To overcome the problem of solving for two unknowns in a single equation, Spokas uses a first order decay (FOD) model to estimate the second of the two unknowns, Gas Generated, so he can solve the mass balance equation. Although the variant used by Spokas breaks down one of the indicated variables, L_o, by its component parts, the original base version of the FOD model, which was developed based upon observations at the Scholl Canyon Landfill, is shown in EQUATION 2 (the various later subtle adjustments for things such as lag factors do not affect the substance of the problem).

EQ. 2 • $$Q_i = 2 \times K \times L_o \times \sum_{i=1}^{n} M_i \exp^{-(K \times t)}$$

Where Q_i is the gas generation in year I, Lo is the lifetime gas potential and k is the annual methane generation rate

This means, first, the protocols are not based upon observation as has often been suggested by the proponents of high capture rates. Second, the reasonableness of the modeled result is only as good as the underlying equation is in serving as a surrogate for observations. In addition to its fundamental failure to account for internal moisture levels, there are several reasons why this decay model is not an appropriate tool for estimating gas generation in aggregate or for specific landfills.

Widely Acknowledged Unreliability of Model's Output. Whether or not he deliberately selected only the best landfills, Spokas' non-randomized sample of 0.3% of the population of French landfills is too small and biased, and his input values are too variable, to produce outputs that are useable for a specific landfill. Even the strongest adherents of high capture rates concluded that Spokas' efforts to use the model to estimate collection efficiencies in specific landfills produces meaningless results. For the model's multiple permutations, all of which appear equally valid, produce a such a wide range of equally reasonable outputs for a specific landfill that they are not usable. Indeed, even EPA, which has everywhere else gravitated to the highest guesstimates of collection efficiency, rejected the early Spokas results because of the large variability of the first order's outputs:

> "The results of this study on two landfills reported LFG collection efficiencies of 94 percent and 98 percent. However, at the French facility that reported 94 percent LFG collection efficiency, this efficiency was based on the lowest of three predicted LFG generation levels for that facility. When the highest estimate of LFG generation is used, then the LFG collection efficiency drops to 84 percent. This raises the issue again that a major difficulty in determining LFG collection efficiencies is accurately estimating LFG generation levels."

Memorandum to Brian Guzzone, US EPA, from Chad Leatherwood, Eastern Research Group, Inc., dated November 18, 2002, re: Review of Available Data and Industry Contacts Re: Landfill Gas Collection Efficiency, at p. 2.

Similarly, a Canadian landfill professor, Dr. Shirley Thompson, who otherwise commends first order principles for landfills generally, notes that the final Spokas paper had compared methane recovery data from models "only for a few landfills.

> "This limited approach is inadequate to validate the model for a wide, rather than site-specific application."

Shirley Thompson, *et al.*, "Building a better methane generation model: Validating models with methane recovery rates from 35 Canadian landfills," *Waste Management* 29 (2009), at p. 2086

When even the strongest proponents of high assumptions of gas performance capture rates reject the model's utility in a specific case, substantial questions are raised about whether the model can be considered reliable for estimating gas capture for any specific landfill, or anywhere for that matter.

Later, the error found by EPA and Thompson in Spokas' reliance upon a very small, self-selected sample was graphically illustrated in several tests of the model by others using large, randomized samples. Each of them demonstrated graphically that the dispersion of output values from FOD models is so wide and irrationally erratic that the model could not reliably be used to predict gas generation at a specific landfill.

EPA's 1998 *AP-42* report noted that "[a]lthough the recommended default k and L_o are based upon the best fit to 21 different landfills, the predicted methane emissions ranged from 38 to 492% of actual, and had a relative standard deviation of 0.85." EPA, *AP-42 Compilation of Air Pollutant Emission Factors*, Chapter 2.4 Municipal Solid Waste Landfills (1998), at p. 2.4-64, which may one of the literature's more elastic definitions of best fit.

A published paper that performed a random verification of related modeling of California landfills found a dispersion among 25 major landfills of predicted values for gas collection efficiency from 7% to 100%. (Nickolas Themelis and Prisilla Ulloa, "Methane generation in landfills," *Renewable Energy* 32 (2007), 1243, at 1250.

Last year, the California Air Resources Board conducted a study, that calculated the implied capture rate at 46 California landfills in 2006 based upon the estimate of Gas Generation produced by the first order decay model. The agency found that implied performance varied from 6% to 257%, which was another exceedingly impressive achievement. The unweighted average was 78%, with one standard deviation ranging from 28% to 128% around the mean. The Wisconsin Department of Natural Resources did a similar test and found the same unexplained dispersion of the model's results, on-line at: http://dnr.wi.gov/org/aw/wm/solid/gas/gas.htm#art6.

Effort to Specify Precise Inputs Fail. There are two main dependent variables in the FOD model, L_o, which represents a landfill's cumulative potential for gas generation over its entire biologically active life, and *k*, the annual decay rate, which is multiplied by the lifetime gas potential.

Although EPA suggests a single value of 100 m3/Mg for L_o, EPA, *AP-42* (2008), *op. cit.*, at p. 2.4-6, the agency cautions that there is extremely wide variation at individual landfills from 6 to 270 m^3/Mg. *Id.*, at p. 2.4-6. For *k*, EPA recommends a value that ranges from 0.02 to 0.3, or a factor of 15×, depending upon local precipitation and on whether the site is operated as a dry tomb or wet cell. *Id.*

Spokas would presumably argue that he has used an actual waste composition study in an effort to control for that variability in L_o, but he does not appear to have succeeded. What he did was one waste composition study to identify the fraction of decomposables at one French landfill, and then he calculated a site specific L_o for the other two landfills in his study, presumably using the IPCC equation in *Reporting guidelines on annual inventories* (2006), at p. 3-9.

But, in fact, he only had one composition study from northeastern France, which his reports suggests exhibited very high variability among wastes in different cells at the site. He proceeded to assume that, (i) a single observation taken once applies across the entire time the site was open; (ii) one landfill's data also accurately described the waste composition in the other two landfills in the opposite western side of the country; and (iii) his particular data set of conversion factors for very broad discard categories – even though the distribution for the group in his composition study may haven been different – provides an accurate, single point estimate of gas potential, rather than wide ranges of their own. Spokas, *op. cit.*, at 519. All of those assumptions are, on their face, highly questionable.

In the end, with the multitudinous value judgments Spokas applied, the imputed L_o value he inferentially used appears to have been 71 m^3/Mg, which is significantly less that EPA's initial 170 m^3/Mg, EPA, *Turning a Liability Into an Asset* (EPA 430-B-96-0004, 1996), at p. 2-6, and also EPA's later revision to 100 m^3/Mg, *AP-42* (2008), *op. cit.*, at 2.4-6. As noted, there is no reliable means to objectively validate one estimate for L_o against another. However, if a decision is made to use a lower estimate for gas generation, then the implied gas collection efficiency will appear to be higher.

Therefore, contrary to Spokas's view that this protocol "enabled an accurate model to be customized for each site," Spokas, *op. cit.,* at p 519, a survey of these efforts to build an L_o value with the use of site specific waste composition data still vary by more than *three* times from 100 to 310 m^3/Mg., Reindart, *op. cit.,* at p. 3-2, while even "[s]mall variations in the D[ecomposable] O[rganic] C[ompound] inputs can result in large variations in the overall methane estimates." Shirley Thompson, *Review of Existing Landfill Methane Generation Model: Interim Report* (November 2005), at p. 16.

The same points pertain to his attempt to use a single waste composition study across three widely separated landfills to calculate a value for *k* based upon, again, his point estimates of half-lives of very broad categories of organic discards. Here his value for *k* appears to convert to 0.052. But, even more important, the real-world decay rate applicable for a landfill in each phase of its life will vary dramatically as a function of moisture levels, see ENDNOTE 9, which Spokas completely ignores.

Other Uncontrolled Sources of Variation. Moreover, there are many more sources of variation that Spokas fails to control for that make his claims of either precision or accuracy questionable. While he prefers one form of the first order decay equation, because of a 10 year old study, there are nine other accepted adaptations of the first order decay structure to landfills, each of which has it own studies claiming their superiority, which were performed after the decade old review Spokas considered. Each model, of course, produces very different results. 40 CFR §60.753. Debra Reinhart, *First Order Kinetic Gas Generation Model Parameters for Wet Landfills* (EPA-600/R-05/072)(June 2005), at p. 2-2; Spokas, *op. cit.*, at p. 519.

Methane Concentration Ratios Vary Widely. Finally, the underlying regression data base and the differential equations used to compute the first order decay model actually predict total landfill gas generation, not the methane fraction of that gas. The user of the model inserts his or her own assumption into the equation for this ratio, which by custom, not observed data, is assumed to be not just 50%, but also a constant 50% at all times.

However, the concentration of methane in landfill gas is not, in fact, a constant 50% or any other value of total predicted gas generation, as Spokas assumed, but rather, it widely varies among landfills and over time. A study by the California Air Resources Board found that, among the 46 major landfills in the state, and averaged over a five year period, methane concentrations ranged from 29% to 59% among its sample of landfills. California Air Resources Board, Staff Spreadsheet Titled Landfill Survey Data Public (2010), released in response to a Public Records request by Californians Against Waste. These observations parallel earlier published findings of methane concentration in landfill gas of 35%-60% by the Department of Energy. EIA, "Growth of the Landfill Gas Industry," Chapter 10 of the *Renewable Energy Annual Report* (1996).

[6] Banister, *op. cit.*, at p. 26; Kurt Spokas, et al., "Methane mass balance at three [French] landfill sites: What is the efficiency of capture by gas collection systems," 26 WASTE MANAGEMENT 26 (2006), at p. 516.

[7] First Order Draft of FAR Chapter 10, at p. 10.

[8] Hans Oonk, Expert Review of First Order Draft of Waste Chapter to IPCC, *Fourth Assessment Report*, at Comment 10-38.

[9] Anaerobic decomposition in a landfill only occurs when there are high moisture levels, as much as 75%. However, only 20%-25% moisture, concentrated in localized pockets, is entrained in the incoming wastes. Tchobanoglous, *op. cit.,* at pp. 72-73 and 393. Others suggest that optimal range lies between 40% - 70%. Debra Reinhart and Timothy Townsend, *Landfill Bioreactor Design & Operation* (Lewis Publishers, 1998), at p. 140. Still others have done research indicating full methane conversion does not proceed until moisture levels reaches 60%-70%; G. J. Farquhar, "Gas Production During Refuse Decomposition." 2 *Water, Air and Soil Pollution* 9, at pp. 483-495 (1973); or require moisture at least 75% for optimality, Sally Brown, "Putting the Landfill Energy Myth to Rest," *BioCycle* (May 2010). *See, also*, 67 FED. REG. at

p. 346462 (May 23, 2002).

[10] ⏏ For vacuum-based gas collection systems to work properly, there must be a seal, or final cover, on top of the landfill to prevent oxygen from the surface also being drawn into the piping, which would create flammable conditions. To prevent that, the negative pressures used to extract gas often have to be damped or shut down, significantly lessening the system's effectiveness, a fact that is compounded as the density of the gas wells continues to be reduced in practice. 40 CFR §60.753. Debra Reinhart, *First Order Kinetic Gas Generation Model Parameters for Wet Landfills* (EPA-600/R-05/072)(June 2005), at p. 3-2. Susan Thornloe (EPA/NRMRL), *Innovative Air Monitoring at Landfills Using Optical Remote Sensing with Radial Plume Mapping* (February 22, 2007), at 4. *AP-42* (2008), *op. cit*., at p. 75; Daniel Duffy, "Landfill Gas to Energy: Means and Methods," *MSW Management* (January-February 2010).

[11] ⏏ However, once that cover is installed so that the collection system can work as designed, no more precipitation, which is necessary to recharge the gas fields to sustain decomposition and gas generation, can infiltrate into the landfill. Also, much of the gas that is extracted, by weight, is water vapor, which causes any landfill put under the influence of negative pressures to be rapidly dehydrated after it is covered. With 100% saturation, at 40° C (104°F), the condensate is 51% by weight of the weight of the gas, according to standard Humidity Tables.

[12] ⏏ Although gas is generated shortly after waste emplacement, gas systems are not required to be installed until five years afterwards. 40 C.F.R. §752(b)(2)(A)*(2)*.

Then the systems are in place for the period of time a cover is installed, but they are withdrawn from service before the end of the 30-year post-closure period. 40 C.F.R. §60.752 (b)(2)(, (B) and (C).

Other field data shows there remains a substantial fraction of decomposables in the closed landfill that will resume generating gas after maintenance ultimately ends and the cap inevitably fails." Chris Zeiss, et. al., "Moisture Flow Through Municipal Solid Waste: Patterns and Characteristics, 22 J. ENV. SYSTEMS 211, at 227 and 228 (1992). Debra Reinhart, *Prediction and Measurement of Leachate Head on Landfill Liners,* Florida Center for Solid and Hazardous Waste Management (Report #98-3) (1998), at p. viii. According to Zeiss, infiltrating runoff courses through narrow channels, rather than being diffused through the waste mass, and reaches only 28% of the decomposables in the landfill.

[13] ⏏ Spokas uses the first order decay model to estimate Gas Generation, primarily during the middle period. But, as discussed in the text, organic discards in a landfill do not decompose in a constant decay function, oblivious to whether the necessary preconditions exist in the surrounding environment. Instead, anaerobic decomposition dramatically slows when the site is too dry (or oxygen infiltration too great) for methanogenesis to occur. That is the reason why the facilities were dubbed "dry tombs" when the era of lined landfills was inaugurated with the intent of walling the wastes off with barriers from liquid intrusions. Yet, none of the first order equations used to model gas generation account for whether the key dependent variables – i.e. whether there is adequate moisture to generate any significant gas in a given year. M. Sinan Bilgili, *et al.*, "Evaluation and modeling of biochemical methane potential (BMP) of landfilled solid waste: A pilot scale study," 100 BIORESOURCE TECHNOLOGY, 4976 (2009). In the middle period, when there is not sufficient moisture in the sealed landfill, the carbon that has not decomposed, and is not stored as lignin, will tend to remain and carry over to the time when the site is closed, which would make the first order model inapposite.

The first attempt to apply the generic first order decay model to landfills was done at the Los Angeles Sanitation District Scholl Canyon landfill, and all of the variants that follow use the same underlying formula shown in EQ. 2 found in ENDNOTE 4.

As shown, there is no variable to account for changes in internal moisture levels inside the waste mass in a given year, nor how internal moisture levels affect methane generation over time. Nor do any of the 10 modifications to the core equation proposed by others add any factor for moisture. Reinhart (2005), *op. cit.* at pp. 2-3 to 2-8.

Recent modifications to EPA's emission factors for landfills have provided an adjustment to the dependent variable, *k*, to reflect whether the landfill is located in an arid or non-arid region (i.e., *k* =.02 when there is <580mm average annual precipitation and 0.04 when there is >580 mm annual precipitation. *AP-42* (2008), at p. 2.4-6.

But, precipitation outside a landfill, which is often covered, is not a valid proxy for moisture levels *inside* the waste mass, because the extent to which rainfall infiltrates and is distributed throughout the landfill depends, among other things, on the following factors that are not accounted for in the revised model:

① Whether there is a low permeable cover;
② Whether outside liquids are added;
③ Whether leachate is re-circulated;
④ The waste's composition, its overall and distributed heterogeneity, and how densely the wastes are compacted;
⑤ The effectiveness of the leachate collection system;
⑥ Ambient temperature and transpiration; and
⑦ The waste mass, site geometry and surface grading practices.

All of these significant intervening factors, which directly implicate any relationship between rainfall and internal moisture levels, are simply ignored by the way the variable is specified. The result is to make the underlying analysis of rainfall differences relatively meaningless as a predictor of moisture actually inside, and the extent it is distributed within, the landfill. A data source has been selected, apparently for its measurement reliability between regions and over time, in an effort to approach precision, for data on internal moisture levels is lacking. But, it also seems to have been done without regard for accuracy, which apparently has not been considered.

Though moisture has not been correctly or meaningfully applied in any of the FOD studies used to support very high capture rates, in the 2008 revisions to AP-42, EPA proposes that a k value of 0.3 be used for wet landfills. EPA, *Background Information Document for Updating AP42 Section 2.4 for Estimating Emissions from Municipal Solid Waste Landfills* (EPA/600/R-08-16, 2008), at p. 77. If this new value that is 15× larger were applied, that would represent an advance from current practice, which ignores internal moisture conditions. However, the 2008 revision fails to go the final and critical step to recognize that the higher k is a dependent function of time phases. Thus, in the middle period after the landfill is sealed, and the collection systems are functional, the waste mass quickly dehydrates and gas generation slows substantially.

The effect of ignoring moisture and its variation over time is to assume far more Gas Generation than actually will occur during the middle phase of a landfill's life, after it is capped, but before maintenance ends following closure and the cover degrades. Inasmuch as that is the time period that is seriously considered by Banister and Sullivan, the effect is to very significantly overestimate capture rates.

[14] ⏏ IPCC FAR, at p. 600. A complete copy of the chapter can be found on-line at: http://www.ipcc-wg3.de/publications/assessment-reports/ar4/.files-ar4/Chapter10.pdf. Banister and Sullivan attempt to dismiss the IPCC's conclusions with the following claim:

> "To clarify, the 20% value quoted by the IPCC represents a global average, not a US average. There are numerous inaccuracies associated with this position, which clearly demonstrate that the 20% value has *no relevance for landfills in the US.*" Banister, *op. cit.*, at p. 28 (emphasis added).

However, the record does not disclose any factual basis for their argument. The Panel's work papers state that the comment the IPCC adopted specifically referenced "the Dutch experience," which is not the undeveloped part of the worlds. Hans Oonk, Expert Review of First Order Draft of Waste Chapter to IPCC, *Fourth Assessment Report*, at Comment 10-27. In general, landfill air regulation is significantly stricter in the Netherlands, than in the US, covering all landfill and not just the largest.

Moreover, it is not correct to suggest that the 20% figure represents a global average value that was pulled down by a heavy penalty for lower gas collection in the Third World. Because most landfills in the underdeveloped world are shallow, frequently burned, open dumps – like those that were prevalent in the U.S. during the most of the 20th century – they tend to not create the anaerobic conditions, which are necessary for major volumes of methane to be created. Methane from garbage is, ironically, largely an unintended consequence of the liners used in the developed world to reduce groundwater contamination. Norwegian State Pollution Control Agency, *Methane emissions from solid waste sites* (TA-2079/2005, 2005) at p. 6. This is why the IPCC's waste reporting guidelines reduce estimated methane emissions from open dumps in the undeveloped world with a Methane Correction Factor (MCF) in order to "account[] for the fact that unmanaged S[olid] W[aste] D[isposal] S[ystems] produce less CH_4 from a given amount of waste than anaerobic managed SWDS." IPCC, *Guidelines for National Greenhouse Gas Inventories*

(2006), Solid Waste Disposal Chapter, at p. 3.14

[15] ⏏ In this graph, as a matter of convenience only, peak gas collection efficiency is conservatively assumed to be 50%, based upon the high end of the range reported by independent experts in published papers, which extends from 34% to 50% and averages 40%. See, e.g., Forbes McDougall, Peter White, *et al., Integrated Solid Waste Management: A Lifecycle Inventory* (Aspen Pub. 1999), at p. 275 [40%]; European Commission, *A Study on the Economic Valuation of Environmental Externalities from Landfill Disposal and Incineration of Waste* - FINAL APPENDIX REPORT (October 2000), at p. 144 [40%]; and Ofira Ayalon, *et al.*, "Solid Waste Treatment as a High-Priority and Low Cost Alternative for Greenhouse Gas Mitigation," 27 *Environmental Management* 5 (May 2001), at p. 699, TABLE 1 [50%]; Riitta Pipatti and Margareta Wihersaari, "Cost-Effectiveness of Alternative Strategies in Mitigating the Greenhouse Impact of Waste Management in Three Communities of Different Sizes,"*Mitigation and Adaptation Strategies for Global Change,* at p. 344 (1998) [40%]; Nickolas Themelis and Priscilla Ulloa, "Methane generation in landfills," *ScienceDirect-Renewable Energy* (April 2006), at p. 8 [34%]; Hans Williamson, "Production and Use of Landfill Gas: Energy Recovery," Paper for International Conference on Solid Waste Management & Technology (Lisbon, October 1997) [25% - 50%]; Region 9 EPA, *Ideas for Consideration to Strengthen WARM Model* (2007), at p. 1 [30%], and Comments by the Massachusetts Department of Environmental Protection, Mandatory Greenhouse Gas Reporting Rule: EPA's Response to Public Comments, Volume 36 (Subpart HH), at p. 42 [40%].

In any event, as Oonk has pointed out, the fact that so little gas is generated during this middle period means that, on a weighted basis, collection performance at this time only has a minor impact on the integrated rate. Changing the graph to assume 90% instead of 50% collection efficiency when the cover is installed would only increase the lifetime rate by an insignificant four percentage points. Oonk's point to the IPCC is that, because so little of the lifetime gas is generated during this time, the extensive discussion by industry claiming higher instantaneous capture rates is largely irrelevant to the key integrated rate.

[16] ⏏ Dry tomb and wet cell landfills will vary slightly in their curves, but that fundamental point remains the same, because, as discussed in more detail later, landfills are so heavily compacted that infiltrating moisture is confined to narrow channels with limited paths of flow. Zeiss, *op. cit.*, at p. 228. Field observations confirm that the additional distribution of moisture with leachate recirculation is not as great as had been anticipated, and the additional near-term gas generation that does occur will be offset by degraded collection efficiency. J.W.F. Morris, et al., "Findings from long term monitoring studies at MSW landfill facilities with leachate recirculation", 23 WASTE MANAGEMENT (2003), at p. 653.

[17] ⏏ R. Baulmler, "Spectroscopic and wet chemical characterization of solid waste organic matter on different age landfill sites," 37 J. ENV. QUAL. 146, 151 (2008).

[18] ⏏ 40 CFR §60.752(b)(2)(A)*(2)*.This delay in the time to install gas systems from the 2 years in the proposed rule, to 5 years in the final rule, with its serious implications for fugitive emissions, was not defended by EPA as being technically based. Rather, the weakening was described as a political compromise for the benefit of the landfill industry in order to accommodate their desire for mega-sized landfills, which were hundreds of feet high and took far longer to fill. 61 FED. REG. 49 (March 12, 1996), at p. 9911. The rule also provides for a shorter 180 day time frame following the cell reaching 40% moisture for the installation of gas systems in bioreactors. 40 CFR §63.1947(a)(2). However, only a handful of the more than 2,000 permitted MSW landfills are bioreactors.

Banister and Sullivan imply ("daily cover soils oxidize methane to a greater degree than many low-permeability final-cover soils") that most of the methane during this time will be oxidized by the 6" of dirt hastily and unevenly laid for the traditional daily cover, at p. 32, which is one of two options at day's end under the Subtitle D rules. 40 CFR §258.21(a).

However, for one thing, the controlled tests of oxidation that they rely upon generally used *12"* of compost in temperate and highly controlled, and often almost hot house-like, conditions, in order to provide sufficient depth, microbial types and porosity to create an oxidizing layer. See, *e.g.*, P. M. Czepiel, *et al.*, "Quantifying the effect of oxidation on landfill methane emissions," *Journal of Geophysical Research* (July, 20, 1996), at p. 16,720.

But, more salient, most landfills have converted to alternative daily covers (ADC) since the mid 1990s, which are another, and lower cost, option permitted by the rule, 40 CFR §258.21(b), because ADC saves about 10%-15% of the total airspace, Daniel Duffy, "The Impact of ADC: Maximizing landfill profits by minimizing airspace utilization rates, *MSW Management* (March-April 2010) and R. Haughey, "Landfill alternative daily cover: conserving air space and reducing landfill operating cost," 19 WASTE MANAG RES 89 (2001). Primary types of ADC are tarps, foams or auto shredder fluff. 40 CFR §258.21(b). It is challenging to comprehend how methane will be oxidized by these media, which Duffy points out, "utilizes little or no airspace," and many of which, like the common tarp, are withdrawn at the start of the following day and waft to let gas escape even when down.

Yet, Banister and Sullivan's broad brush statements ("[biocovers] serve as an excellent additional control measure for methane," Banister, *op. cit.*, at p. 32) may lead a casual reader, who is not conversant with the literature to assume that compost covers can substitute for active gas collection systems. There would be no basis in fact for that unsupported inference.

Indeed, the literature that they cite clearly states that these compost soils are overwhelmed when emissions at more than low flux rates are released, as would shortly be the case in the absence of active gas collection, especially in wet cells. Jeffrey Canton, *et al.*, "Methane Oxidation in landfill Cover Soils, is a 10% Default Value Reasonable?," 38 J. ENVIRON. QUAL. 654, at p. 661:

> "As outflux rates increase, their percent oxidation decreases and they can become overwhelmed with methane. As methane emission[s] increases, percent oxidation decreases."

Unfortunately, neither can effective gas collection be combined with oxidation sites in order to reduce the emission rates to levels that biocovers can process. On the one hand, oxidation is not realistically possible with low permeable covers (e.g. a composite geomembrane/clay or 3 feet of clay) because, instead of being diffused, gas escaping through tight covers is released primarily through localized cracks at high fluxes which, again, overwhelm the microbes' capacity to oxidize methane. Czepiel, *op. cit*, at p. 16721; G. Borjesson, *et al.*, "Effects of gas extraction interruption on emissions of methane and carbon dioxide from a landfill and on methane oxidation in cover soil," 26 J. ENV. QUAL. 4, at p. 1182; AEA Technology, *Methane emissions from UK landfills* (UK Department of the Environment, Transport and the Regions, 1999), at p. 2-9; D.K. Powelson, "Methane oxidation in biofilers measure by mass-balance and stable isotope methods," 41 ENV. SCI. TECH. 620 (2007), at p. 624.

On the other hand, a landfill operator seeking to maximize oxidation cannot eliminate installation of a low permeable cover after the cell reaches final grade to permit diffusion of the gas emissions, because gas collection requires the seal that a cover creates in order to operate effectively. Reinhart (2005), *op. cit.*, at p. 3-2. For absent a cover, the collection system's vacuum forces will also suck air from the surface that, mixed with methane, creates flammable conditions that short circuits the system. 40 CFR §60.753. Also, see, ENDNOTE 24.

Presumably because of the documented incompatibility of oxidation and gas collection, even Bogner, an otherwise prominent proponent of biocovers, recognizes their limited applicability in practice to only "older landfills, where it is not cost-effective to install a GCCS [or] to many developing countries." Jean Bogner, *et al.*, "Effectiveness of a Florida Landfill Biocover for Reduction of CH_4 and NMHC Emissions," 40 ENV. SCIENCE AND TECH 1197 (January 2010).

In addition, while oxidation in highly controlled conditions, which is not representative of the real world, has shown benefits from parallel reductions in some but not all of the hazardous air pollutants, Bogner (2010), *op. cit.,* at p. 1199, other testing has also raised new and potentially highly significant climate concern.

For methanotrophs, which are the microbes most associated with oxidation, according to the latest research, "may be associated with N_2O formation, another greenhouse gas with a global warming potential of 289 times CO_2 over a 100-year period [compared to CO_2].

> "Nitrogen rich environments (such as covers made of organic soil substrates or composts) and alternating aerobic and anaerobic zones are both factors that are believed to stimulate methanotrophic N_2O production." Marion Huber-Humer, *et al.*, "Biotic systems to mitigate landfill methane emissions," 26 WASTE MANAGEMENT & RESEARCH 33 (2008), at p. 35.

Since nitrous oxides exhibit 12× the capacity to warm the atmosphere as methane, if this research continues to be corroborated, the slightest increase in N_2O would overwhelm whatever real world net benefits oxidation provides in reducing CH_4 releases.

Finally, Banister and Sullivan put forward no data to specify what proportion of landfills are, in fact, using biocovers in lieu of active collection systems. Rather, they only opine that some unspecified number could do so, which is a thought that has no practical application in an analysis of real world capture rates.

A reading of the literature on the carefully controlled tests of methane oxidation does not support the extravagant claims made by Banister and Sullivan, any more than a researcher's findings that, because he can grow winter hot house vegetables, that means tomatoes can be grown in a North Dakota December.

For all of these reasons, it is exceedingly difficult to ascribe any weight to their claims for oxidation. At the present time, the possibility of biocovers substituting for gas collection systems is moored to the realm of pure speculation. Moreover, a brief recapitulation of the history of the 20th century's engineered landfills dispels their attempt, notwithstanding all facts to the contrary, to imbue oxidation with the magical powers of some sort of *deus ex machina*. Rather, it may be better seen as just the latest attempt at the end of a long line of earlier failed "solutions." Included in that history is the landfill industry's earlier designation as "state of the art" for the following solutions that later failed:

- *Land*fills (i.e. discarding wastes into marshes and wetlands to recover land for development, which is the derivation of the word "landfill") → In addition to creating developable land, garbage leachate leaked into surface and ground waters.

- Sanitary landfills (i.e. daily dirt cover and compaction intended to control vermin and litter) → While they somewhat lessened disease vectors, they also inadvertently created the first tighter conditions that led to methane generation and lateral subsurface migration into adjoining buildings that caused deadly explosions, while, at same time, failing to protect groundwater. This later led the first and most famous sanitary landfill at Fresno onto the Superfund list.

- Natural attenuation landfills (i.e. reliance upon soil underlying a landfill to attenuate pollutants) → Too many naturally attenuating landfills also wound up on Superfund lists.

- Clay liners (i.e. 2 to 3 feet of compacted clay liner intended to protect groundwater) → South Coast Air Management District tests found that they only marginally slowed, and did not prevent, leaks into groundwater.

- Zoning restrictions (i.e. limiting development within 1,000 feet of landfills to prevent gas explosions) → Shortly thereafter an explosion in an armory adjoining a landfill in Winston-Salem nearly burned 25 soldiers to death.

- Composite bottom liners (i.e. a plastic sheet along the bottom cavity in the ground underlaid with clay to protect groundwater and prevent lateral migration of methane) → While migration was blocked from migrating into adjoining buildings, gas releases shifted, following the remaining paths of least resistance, into the atmosphere and adding to greenhouse gas loadings of concern to global warming.

- Composite top liners for cover (i.e. plastic sheet on top of clay overlain by soil layer at surface to prevent bathtub effect) → In experience with customary steep side slopes, the soil sloughed off the slippery plastic and fed the interest in alternative final covers whose durability over many decades untended is questionable.

- Mega-sized landfills (i.e. industry claimed and EPA concurred that replacing small local landfills with very large regional facilities would provide the necessary size to acquire greater operating skills) → Scaled up landfill 100 times larger led to significantly greater methane generation per ton and delayed installation of final covers necessary for gas collection to work. Also, the sheer mass created a whole new failure mechanism in the form of massive land slides at landfills that become "too big to fix."

This disturbingly long track record of yesterday's state-of-the-art strategies creating whole new threats to the environment, as well as winding up on Superfund lists, appears to more likely be an indication of a failed, than of an improving, technology.

For a more on oxidation, see ENDNOTE 40.

[19] 40 CFR Part 258, and especially 40 CFR §§258.28 and 258.40. See, also, William Rathje, *Rubbish!: The Archaeology of Garbage* (HarperCollins NY 1st ed., 1992), at p. 115.

[20] Christopher Campman and Alfred Yates, "Bioreactor Landfills: An Idea Whose Time Has Come," *MSW Management* (Sept/Oct. 2002), at TABLE 1.

[21] Sherien A. Elagroudya, *et al*, "Waste settlement in bioreactor landfill models," 28 WASTE MANAGEMENT 2366 (Nov 2008).

[22] Reinhart (2005), *op. cit.,* at p. 2-2.

[23] First order decay model run for 15 years with the following inputs: Lo = 100 m^3/Mg; $k = 0.04$ (dry) compared to $k = 0.3$ (wet), taken from EPA, *AP-42* (2008), *op. cit.*, at p. 2.4-6. The quantity of methane estimated to be generated over 15 years increased by 3.2 times, while total gas generation increased by 2.4 times.

[24] See, *e.g.*, including along side the related statements: Susan Thornloe (EPA/NRMRL), *Innovative Air Monitoring at Landfills Using Optical Remote Sensing with Radial Plume Mapping* (February 22, 2007), at 4:

> "Alternative covers or porous materials are used to promote infiltration which results in larger loss of fugitive emissions."

Also, see Reinhart (2005), *op. cit.*, at p. 5.2:

> "Even if a gas collection system is operational, a lack of a cover will reduce collection efficiency."

Even Sullivan has conceded this point in another paper, Solid Waste Industry for Climate Solutions, *Current MSW Industry Position and State-of-the-Practice on LFG Collection Efficiency, Methane Oxidation, and Carbon Sequestration in Landfills* (July 2007), at 10:

> "Furthermore, a site with a collection system that is used solely for energy recovery is usually not capable of achieving as high a collection efficiency as compared to one that is compliant with NSPS regulations."

Banister and Sullivan ultimately draw the opposite conclusion, because they contend, "many [unspecified number of] landfills install controls early." Banister, *op. cit.*, at p. 32. While, technically speaking, that is nominally true, the full reality is usually something quite different than the statement appears to suggest, because the particular controls actually used are marginally effective.

In fact,, flexible horizontal drain pipe, which has been perforated, is sometimes laid down in wet cell landfills with each day's lift in order to later provide a channel through which leachate can be re-injected into the waste mass. Leachate recirculation is periodically paused when the waste saturates and reaches its field capacity in order to wait for the mass to drain, after which recirculation can resume. During those interruptions, negative pressure can be applied to co-utilize the same pipes in order to also intermittently pull gas. Debra Reinhart and Timothy Townsend, *Landfill Bioreactor Design & Operation* (Lewis, 1998), at p. 132.

Obviously, while some gas collection does occur, that is not the same thing as a functioning gas collection system, at least not in the same sense that occurs in the traditional, and significantly more effective, rigid vertical wells, surrounded by gravel packs, that have long been used to capture gas. Unfortunately, the standard wells usually cannot be installed in wet cell landfills because the differential settlement from accelerating decomposition will cause them to tilt and snap. Unfortunately, not only is the expendable drain pipe used in their place only intermittently used to collect gas, but also, these types of flexible pipe, like those used in field drains, are only able to sustain negative pressures whose zone of influence is a third that of the vertical wells; they are prone to collapse from the heavily recompacted overburden; and they operate in saturated conditions in which gas capture is exceedingly difficult. AEA Technology, *Methane emissions from UK landfills* (UK Department of the Environment, Transport and the Regions, 1999), at p. 2-9. Then, at other times, ponds or gravel filled trenches are also often used to create a pathway for recirculating leachate, neither of which may purport to collect gas at all. Debra Reinhart, *et al.*, *Landfill Bioreactor Design and Operation* (Lewis, 1998), at p. 85.

In one sense, it may seem better to have some gas collection than none in the initial five years, but many cross-currents tend negate that benefit. For one thing, this very poor co-utilization style of gas collection system also operates in the latter part of the First Phase, when dry tomb facilities have installed those far more effective vertical wells, and when there is substantially more gas to be collected. For another, as discussed elsewhere, during this time period when wet cell landfills exhibit poor capture, they also boost methane levels and time-shift gas from the future to the present.

Furthermore, when wet cell practices are employed in conjunction with LFGTE, the motivation to optimize the economics of energy recovery, as Oonk also advised the IPCC, competes with the socially desirable need to maximize collection, which leads to further deterioration in gas capture. Hans Oonk, Expert Review of First Order Draft of Waste Chapter to IPCC, *Fourth Assessment Report*, at Comment 10-27.

As one example, energy landfills are 50 times more sensitive to any oxygen being drawn from the surface into the gas pipes, and they have to damp or shut down at far lower levels of oxygen infiltration than dry tomb landfills due to imperfections in the cover, which destroy the anaerobic methanogens. This is because dry tomb landfills need only be concerned if oxygen levels exceed the Lower Explosive Limit of 5%, or risk fire, LFGTE landfills can only tolerate $^{1}/_{50}{}^{th}$ of the level of oxygen from the surface before the methane levels that they harvest fall off dramatically.

Finally, because gas extraction also removes water vapor, and dehydrated landfills also cannot produce much methane, gas wells are intermittently damped or shut down to give the gas fields time to recharge from rains. Don Augenstein *et al.*, *Improving Landfill Methane Recovery – Recent Evaluations and Large Scale Tests*, Presentation to Methane to Markets Partnership Expos (2007), at p. 3. Solid Waste Industry for Climate Solutions, *Current MSW Industry Position and State-of-the-Practice on LFG Collection Efficiency, Methane Oxidation, and Carbon Sequestration in Landfills* (July 2007), at 10.)Solid Waste Association of North America, *Comparison of Models for Predicting Landfill Methane Recovery* (1998), at p. 2-3.AEA Technology, *Methane emissions from UK landfills* (UK Department of the Environment, Transport and the Regions, 1999), at p. 2-20.

[25] Timothy M. Lenton, *et al.*, "Tipping elements in the Earth's climate system," 105 PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES 6, at pp. 1786-1793. Johan Rockstrom, et. al., "A safe operating space for humanity," *Nature* (September 2009), at pp. 472-475.

[26] The assumptions used to calculate the increase in methane generation associated with wet cell practices in order to run the first order decay model were: (i) a "*k*" value, used to estimate increases gas generation as a function of increased moisture levels, changes from 0.04 to 0.3. *AP-42* (2008), *op. cit.*, at p. 2.4-6. Reinhart (2005), *op. cit.*,at p. 5-2. Methane ratios were increased conservatively from 43% to 58%. See ENDNOTE 1. Total landfill gas generation is estimated by the model with these changes in assumptions to increase in the near term over an assumed 15 year life by 2.4×, and methane, by 3.2×.

According to, K. Reddy, "Geotechnical Aspects of Bioreactor Landfills," *IGC* (2006), at p. 79, 90, in the best case of a bioreactor landfill, the enhanced cell captured 75% more gas than the control cell per ton of waste in place. When 0.3 is used for the *k* value in the case of a wet cell landfill, compared to 0.04 for a dry tomb landfills, gas generation is increased by 3.2 times in the first 15 years. When gas production is increased by 3 times, while gas capture only increases by 75%, that computes to a decline in collection efficiency of 45%.

Sullivan separately makes the claim that collection efficiency, while 0 prior to the installation of a gas collection system, exhibits the following efficiencies after gas collection is installed:

> "50-85% (mid-range default = 68%) for a landfill or portions of a landfill that are under daily cover with an active LFG collection system installed but does not have a Resource Conservation and Recovery Act (RCRA) Subtitle D equivalent liner;
> "85-99% (mid-range default = 92%) for a landfill or portions of a landfill that contain intermediate or an engineered final soil cover with an active LFG collection system but does not have a RCRA Subtitle D equivalent liner, and;
> "95-99% (mid-range default = 97%) for landfills that have a RCRA Subtitle D equivalent liner with an active LFG collection system. For the most part, these are modern state-of-the-art landfills that have been designed and constructed from the ground up with modern RCRA Subtitle D equivalent liner systems and gas collection systems that were specifically designed and installed as early as possible in the landfill units operating life. These landfill units were typically constructed after 1991."

Patrick Sullivan, “Current MSW Industry Position and State-of-the-Practice on LFG Collection Efficiency, Methane Oxidation, and Carbon Sequestration in Landfills”(Monograph)(Jul 2007), at p. 10.

The apparent source for these values relating to landfills before they are finally covered is the Spokas paper. However, apart from the fatal flaws in that study’s methodology, discussed in more detail earlier, the only landfill described under conditions in which gas collection is installed with a temporary cover is the Lapouyade landfill in France. But, in order to conclude that this facility achieved 92.5% gas capture under a temporary cover, the author had to assume, without stating any documentation, that the landfill somehow temporarily stored 68% of the gas that he estimated to have been generated. *Id.,* at p. 522 (Table 3). In view of the fact that landfills do not store any of the gases they generate, other than for temporary periods of high barometric pressure, Agency for Toxic Substances and Disease Registry, *Landfill Gas Primer - An Overview for Environmental Health Professionals*,” Chapter 2, at p. 9 (2001), this extremely large assumption underlying Sullivan’s enumeration appears dubious.

Mr. Sullivan is correct that EPA recently adopted his numbers as a part of its Mandatory Greenhouse Reporting Rule, 74 FED. REG. 56259 (Oct 30, 2009), but that was done without any public notice providing opportunity for others to comment. Whether the agency’s decision was due to the persuasiveness of his views, or to cognitive regulatory capture, see, generally, Willem H. Buiter, “Central Banks and Financial Crises,” *Proceedings of the Federal Reserve Board’s 2008 Jackson Hole Conference*, at p. 497; Siobhan Hughes, “Chief Concedes Drilling Regulator Relied on Industry,” Wall Street Journal (August 12, 2010), is speculative.

Also, of note, when methane production is thus trebled during the First Phase, and capture rates in consequence plunge by 45%, the climate-related impacts are magnified by several magnitudes due to methane’s extremely large Global Warming Potential (GWP).

The key take-way point from the vantage point of global warming is that ten times more methane will be released in the near-term with a shift to leachate recirculating, than a continuation of dry tomb, landfills.

In turn, that one magnitude increase in atmospheric methane levels will add at least 25 times more atmospheric warming potential, than was the case with the earlier dry tombs, or 250 times the status quo. IPCC, *Fourth Assessment Report*: Chapter 2: Changes in Atmospheric Constituents and in Radiative Forcing (2007), at p. 212, which shows methane’s Global Warming Potential as 25 times CO2's on a 100-year basis, and 72 times, on a 20-year basis. Most recently, methane’s warming potential has been more extensively investigated and NASA’s scientists now consider methane to be 34× CO_2 in the long-term, and 105× CO_2 in the near term, after factoring in indirect impacts on the formation of aerosols, which is another greenhouse gas. Drew Shindell, “Improved Attribution of Climate Forcing Emissions,” 326 SCIENCE 716 (2009).

[27] EPA, Response to Comments (Subpart HH), Mandatory Greenhouse Gas Reporting Rule, 74 FED. REG. 209 (October 30, 2009), at p. 72.

[28] 40 CFR §§258.4(a)(2) and 258.60 to 258.61.

[29] 40 CFR §258.61(a).

[30] 40 CFR §§258.60, 25.61 and 258.70 to 258.75. Parenthetically, the rules only reach to minor maintenance issues, such as mowing the grass and occasionally monitoring the wells, not major maintenance, such as eventually replacing a worn out cover, nonetheless possible and very expensive corrective actions.

[31] John Skinner, “Composting and Bioreactors,” *MSW Management* (July/August 2001), at p. 16. Rob Arner, H. Lanier Hickman and Cristine Leavitt, “Dump Now, Pay Later?” *MSW Management* (Sept. 2000). Jeffery Bromme, “Avoiding a Financial Crisis,” *Waste Age*, May 2005, at p. 28.

[32] 53 FEDERAL REGISTER. 168, at pp. 33344-33345 (August 30, 1988).

[33] California Integrated Waste Management Board Staff *Post-Closure Maintenance Presentation* to Board Permit and Enforcement Committee (November 3, 2003), Power Point Slide No. 18.

[34] 46 FED. REG. at pp. 28314-28328 (May 26, 1981). *See, also*, Commission of the European Community*, Management and Composition of Leachate from Landfills: Final Report* (1994), at p. 7, TABLE 1.2. H. Belevi and P. Baccini, "Long Term Behavior of Municipal Solid Waste Landfills," *Waste Management and Research* (1989), at p. 43. Peter Flyhammar, *The Release of Heavy Metals in Stabilized MSW by Oxidation* (Swedish Department of Water Resources, Nov '99), at p. 20 TABLE 10.

[35] The average time when gas systems could be removed from service from among the landfills evaluated by EPA on the proposed rule was 27 years following closure. EPA, *Air Emissions from Municipal Solid Waste Landfills*, at pp. 3-12, Table 3-4. However, subsequent modifications in the final rule in the assumed inputs into the equations used to calculate NMOCs have the effect of further reducing the time that more landfills have to maintain gas collection by 40%, thereby reducing the 27 years to approximately 16 years. The final rule lowered the emission rate cutoff, which set the time when the system could be removed, from 150 to 50 metric tons per year of NMOC, 61 FEDERAL REGISTER 9911 (March 12, 1996), which, if all other things were equal, would have had the effect of making the final rule stricter in this respect. However, as the nominal emission rate was lowered, the default values for calculating the rate were modified, for the reasons described in 58 FEDERAL REGISTER 33790 (June 21, 1993), as shown on the TABLE below.

Changes in Input Factors for Calculation of NMOC Rate Between Proposed and Final Landfill Air Rule

Input Factors	Where	Proposed Rule	Final Rule
k	=methane generation rate/yr	0.02	0.05
L_o	=methane generation potential(m^3/Mg	230	170
C_{NMOC}	=concentration of NMOC(ppmv)	8000	4000

The effect of the changes in default values is to increase the emission rate cutoff value, and hence weaken the standard, by about 40%, or to the equivalent of approximately 125 MT NMOC, when applying the formula given by EPA's for its first order decay model in 40 C.F.R. §60.754(a).

[36] Banister, *op. cit.*, at p. 30.

[37] See ENDNOTE 9.

[38] Again as noted earlier, the known facts also demonstrate that after closure, and for as long as the cap retains its integrity, there is grossly insufficient moisture for substantial decomposition anywhere in the landfill, We know this, again, not only because average moisture levels in the entrained wastes are less than a third of what methanogenesis requires. But also, actual field studies demonstrate that "water flow ... occurs in narrow flow channels [reaching] a total area of 28%." The author points out in reference to that 28% finding, "[c]hanneling effects mean that biodegradation of landfilled waste may occur preferentially along wetted channels where flow, nutrient transport and waste product removal is most intensive while large pockets of waste remain relatively dry." Zeiss, *op. cit.*, at 227 and 228.

Modulating Zeiss's finding in both directions, on the one hand, he does not preclude the possibility that some decomposition could occur, albeit at slower rates, in the dryer areas outside the channels through which leachate preferentially flows. *Id.*, at p. 228. On the other hand, conditions in landfills today will exhibit far more restrictive channelizing effects than when Zeiss did his field measurements. His study analyzed waste samples with an average density of 452 pounds per cubic yard. *Id.*, at p. 220. Modern landfills, on the other hand, have tripled that in-place density since the early 1990s to more than 1,500 lbs./cu.yd., by using heavier compactors with larger and more heavily studded wheels making more passes, by recirculating leachate that increases compressive forces from wetting, and by delaying installation of the final cover to provide more time for settlement before the site is sealed. Penelope O'Malley, "Density, Density, Density," *MSW Management* (July/August 2006), at p. 54; Neal Bolton, "Maximizing Landfill Airspace–the Planning Component," *MSW Management* (October 2008), at p. 40. Substantially higher densities will translate into even more restrictive preferred paths of flow today that what Zeiss found in 1992. Zeiss*, op. cit.*, at p. 216.

Furthermore, the shift to wet cell practices does not seem to have significantly increased the *distribution* of the greater moisture levels to more areas of the waste mass. Even when leachate is recirculated, "the efficiency of ... distributing leachate throughout the waste body in the recirculation cell were [still] low."

Morris, *op. cit.*, at p. 653. Simply increasing recirculation rates and adding outside liquids, by themselves, are too risky because, so long as liquids continue to follow preferential horizontal paths, leachate seeps and sidewall breakouts are likely. Philip McCreanor *et al.*, "Mathematical Modeling of Leachate Routing in a Leachate Recirculating Landfill," 34 Water Resources 4, 1285, at p. 1295 In order to significantly improve liquids distribution in wet cell landfills, the incoming wastes would need to be ground and homogenized, and compaction ratios would need to be reduced by about 60%, *Id.*, at p. 1295; Edward McBean, "Leachate Mounding, Collection Systems, and Monitoring," Designing and Operating Bioreactor Landfills, Department of Engineering Professional Development, University of Wisconsin-Madison (June 2002).

As stated in the prior note, the best data to pinpoint how much of the carbon in the incoming garbage that is decomposed at closure is to count the remaining unsequestered carbon waste mass, but the industry has refused requests that this be done. Until that is evaluated, the Zeiss and Morris data is a reasonable indicator suggesting more than half of the original carbon in the buried solid waste remains latent to later generate a second wave of gas, decades hence, when the cover eventually fails.

[39] There are two types of permitted final covers: a more robust clay/plastic composite cover, and an undefined experimental alternative cover, which in general is porous and follow lighter and less durable designs. More specifically, the final cover may either be a mirror image of the composite clay/plastic liner at the bottom of the facility, or it also can be an undefined experimental "alternative" cover, such as a biocover or evapotranspiration cover. 40 CFR §§258.4(a)(2) and 258.60 to 258.61. As originally promulgated, the closure rules required a cover with a permeability equivalent to the liner. However, in practice, and because the agency permitted steep side slopes in order to maximize air space and thereby lower landfill costs, operators found that they were unable to stabilize the typically mandated composite covers (i.e. a 2 foot clay liner covered by a 60 mill high density polyethylene plastic sheet, and overlain by a drainage and soil layer). 40 CFR §258.60(a). In practice, however, the erosion layer can catastrophically slough off. G. N. Richardson, *Active Gas Control: An Unreliable Aid to Veneer Stability*, First Pan American Geosynthetics Conference & Exhibition (March 2008). Rudolph Bonaparte, *Technical Guidance for RCRA/CERCLA Final Covers* (Environmental Protection Agency Office of Solid Waste and Emergency Response, 2004). Instead of requiring shallower side slopes, from 3:1 (about 19°) to 4:1 (about 15°), in order to provide a less challenging base for stabilization, as several states determined was prudent, see, e.g., NR 506.08 (3) (c), Wis. Admin. Code, EPA encouraged trials of experimental alternative caps. 69 Fed. Reg. 55, at p. 13245 (March 22, 2004).

For those landfills with unproven alternative covers, and which tend to depend upon continuing maintenance, there is, as yet, no reliable basis to make any supportable claims asserting their decades long survival after maintenance ends.

But even for the stronger composite covers, their longevity is also dubious after maintenance ceases. Indeed, a field survey conducted in 2001 by the EPA's Inspector General found that "most" landfill covers began experiencing demonstrable failures before the nominal post-closure period had expired. The Inspector General concluded "landfill caps are only expected to last for 20 years.

> "In our sample, we found several examples of [cover] barriers failing during the first 30 years. *Most* of the states in our sample reported animal or weather-related damage at their sites. Repairs were required at one facility after wild pigs rooting in the near surface soil caused erosion of the landfill cap. In another state, black bears have been a problem. We found other examples of landfill caps eroding, damage to caps due to animal burrows, and a drainage channel being destroyed after heavy downpours. Other sites needed maintenance due to vegetation growth. Additionally, unexpected events other than natural erosion occurred at other sites which required maintenance activities. For example, at one site an automobile drove through the fence surrounding the facility, destroying the leachate treatment system. Another landfill site required repairs after children dug under a fence into a landfill site in order to skateboard on an old truck ramp."

Office of the Inspector General, *RCRA Financial Assurance for Closure and Post-Closure* (2001-P-007) (March 30, 2001), at pp.33-34 (emphasis added).

Most important to note in regard to the Inspector General's investigation is that fact that this study just recorded instances where there was a visible manifestation of breaches at the surface, excluding tears in the synthetic liner beneath the topsoil occurring from other causes not apparent from above, such as from subsidence, roots or faulty installation, which may not provide visible clues.

Because most of even the more durable composite covers are known to soon fail and require maintenance to repair, and maintenance effectively ends 30 years following closure, the industry's claims that caps will survive for a thousand years, Rudolph Bonaparte, *et al.*, *Technical Resource Document: Assessment and Recommendations for Improving the Performance of Waste Containment Systems* (EPA/600/R-02/099, December 2002), at 2-42, are difficult to accord serious consideration.

A long list of former and current government officials and agencies, as well as EPA's formal and repeated declarations in the Federal Register, speak to the fact that landfill barriers will "ultimately fail." 53 FEDERAL REGISTER. 168, at pp. 33344-33345 (August 30, 1988). See, also, Office of the Inspector General, *RCRA Financial Assurance for Closure and Post-Closure* (2001-P-007) (Mar. 30, 2001), at pp. 33. Washington Department of Environmental Protection, *Background Information for Beyond Waste Document* (2004), at p. 3. Testimony of Suzanne Bangert, Director Wisconsin Department of Natural Resources Bureau of Waste Management Before the Assembly Committee on Natural Resources on Clearing House Rule 04-077 (April 27, 2005). John Skinner, "Composting and Bioreactors," *MSW Management* (July/August 2001), at p. 16. Rob Arner, H. Lanier Hickman and Cristine Leavitt, "Dump Now, Pay Later?" *MSW Management* (Sept. 2000).

Even landfills most ardent supporter, Dr. Mort Barlaz conceded that, if society does not levy taxes to maintain the cover in perpetuity after the regulatory postclosure period ends, the caps will fail. Presentation by Prof. Mort Barlaz before the Wisconsin Department of Natural Resources' Landfill Stability Subcommittee of the Leachate Collection System Technical Advisory Committee, on March 1, 2004, in Madison, Wisconsin (emphasis added):

> "You asked if the site will no longer be cap dependent. That's a pretty tall order...I don't in my mind see us working to a situation where we are not cap dependent...If [uncontrolled releases later] did occur, I think we have to go right back to the fact that the cap failed.
>
> "If the cap failed, and if *you* do what we said to do ..., you'd go in and fix the cap.
>
> "Now if you don't believe that *society* has the mechanism to insure that you go back and fix the cap, I personally can't address that. That's a regulatory matter."

Transcript from video tape made by WDNR of the proceeding.

Claims for enduring final covers do not hold up under scrutiny.

40 Oxidation refers to the observed capacity of thick, well maintained compost soils under carefully controlled, nearly hot-house conditions to oxidize low rates of methane emissions that have been carefully diffused before being emitted from landfills. Czepiel, *op. cit.*, at p. 16,720. Canton, *op. cit.*, at p. 658.

Banister and Sullivan's statements concerning late-life oxidation seem to imply that the process will oxidize all or most of the methane generated decades hence, Banister, *op. cit.*, at p. 31, in the event, as the data strongly suggests (but they dispute), there will be a second wave of gas generation. However, they actually qualify their claim to conditions in which emissions are at low levels and are diffused, *Id.*, which necessarily presupposes that the cover does not fail and there is no remaining carbon in the wastes. As discussed in ENDNOTES 38 and 39, neither assumption is factually true.

Furthermore, their implication also fails to account for the previously discussed fact that gas is typically released at the surface of landfills through a low permeable final cover (e.g. a composite liner of 60 mil high density polyethene and/or more than 2 to 3 feet of compacted clay per 40 CFR §258.60(a)), from the inevitable cracks that will occur over the decades after maintenance ends, permitting rainfall to re-enter the site.

As noted, gas released through cracks occurs in high fluxes that exceed the capacity of a dedicated compost layer to oxidize. Czepiel, *op. cit*, at p. 16721; G. Borjesson, *op. cit.*, at p. 1182; AEA Technology, *op. cit.*, at p. 2-9; Powelson, *op. cit.*, at p. 624. Thus, a landfill properly constructed at closure, like in operation, to minimize gas emissions with active collection systems in compliance with 40 CFR Part 60WWW, would not be able to treat methane because the gas would egress at too high a flux to be oxidized.

Finally, Banister and Sullivan claim that landfills should be credited for compost on the surface of a landfill functioning like a sink to oxidize atmospheric methane. Banister, *op. cit.*, at 31. However, they neglect to recognize that the compost for biocovers is normally applied to agricultural lands because of its primary capacity to improve the fertility of and return nutrients to the soil, Aziz Shiralipoura, et al., “Uses and benefits of MSW compost: A review and an assessment,” 3 BIOMASS AND BIOENERGY 3 (1992), at p. 267, and where it presently also serves as a carbon sink. R. Lal, Soil Carbon Sequestration Impacts on Global Climate Change and Food Security,” 304 SCIENCE 5677 (June 2004), at p. 1623. That is the reason why yard trimmings have traditionally been diverted from landfills to composters in the first place. Dan Sullivan, “A Slippery Slope: Bad News Good News on Yard Trimmings Disposal Bans,” *BioCycle* (2010).

To change that optimized practice and, after going to the expense of diverting green wastes from landfills, to turn around and divert the compost produced by composters from crop land to landfills would be as counterproductive as it would be ironic. In any event, moving compost from the farm to landfills would certainly create no net benefit to the Earth’s carbon balance.