

CENTER FOR A COMPETITIVE WASTE INDUSTRY

CRITIQUE OF SCS ENGINEERS' REPORT PREPARED FOR CALIFORNIA'S LANDFILL COMPANIES ON GAS COLLECTION PERFORMANCE

Summary

SCS Engineers were retained by the landfill owners in California to provide their technical basis for claiming gas collection efficiency rates as high as 99% in submittals to the Air Resources Board.

They claim, among other things, that an EPA report supporting its assumed 75% capture rate should be considered as a minimum not an average value; that EPA's rules requiring active gas collection in 1996 resulted in significant increases in performance; and that their studies support those high levels of efficiency.

In fact, the EPA report is invalid, the new source rules did not require any higher levels of performance and their studies are based upon a methodology rejected by EPA and independent reviewers.

The best number to use for capture rates in climate change projections is based upon average lifetime performance which, the Intergovernmental Panel on Climate Change, has stated is "as low as 20%."

Introduction

In July 2007, SCS Engineers (SCS) submitted a report to the California Air Resources Board (CARB), *Current MSW Industry Position and State-of-the-Practice on LFG Collection Efficiency, Methane Oxidation, and Carbon Sequestration in Landfills* (SCS Report). It was prepared for the Solid Waste Industry for Climate Solutions (SWICS), a coalition of landfill owners in California. By claiming that most methane generated in landfills is captured or oxidized, SCS seeks to convince CARB to exclude the waste industry from bearing additional regulatory burdens as part of the early action provisions of AB 32, the state's climate change law.

Quite possibly, an additional reason was to manufacture doubt in the face of recent disclosures described in APPENDIX A that undermined the Environmental Protection Agency's (EPA) 75% capture rate assumption, which CARB preliminarily is using as a default value, and which SCS attempts to now characterize as a lower bound estimate. For investigation had recently disclosed that the 75% number was based upon the assumed performance of the *best* systems on an *instantaneous* basis for the less than half the time that there are functioning collection systems in place. However, in order to assess landfills' responsibility for anthropogenic greenhouse gases (GHG), the benchmark obviously needs to be what *average* systems actually achieve *integrated* over the entire period that landfills generate significant volumes of gas. By positing even higher capture rate assumptions, which also have no factual basis, SCS may be seeking to skew the zone of reasonableness even higher than EPA's increasingly tenuous efforts.

This is to provide the reasons why SCS's claims, which argue that almost no methane escapes from landfills, have no validity and bear no relationship to an independent assessment.

Response to SCS's Claims

SCS makes six major claims in support of extremely high assumptions about the performance of gas collection systems in typical landfills over the prolonged, decades long time frame that they generate gas, most of which time there is no functioning collection system:

- ① EPA's 75% capture rate assumption should be considered the minimum value for collection efficiency, not an average value.
- ② EPA's new source air pollution rules, which took effect in 1998, had the effect of substantially increasing performance beyond that in pre-1998 systems.
- ③ The so-called "sniff test," which is a part of those rules, provides a basis to support very high capture rate assumptions.
- ④ Oxidation of methane that escapes through the soil overlaying closed landfills provides 2½ times the effect as the EPA recognizes.
- ⑤ Much more carbon is sequestered in landfills than EPA has previously considered.
- ⑥ Studies demonstrate very high capture rates are possible.

None of these claims are valid.

SCS's FIRST CLAIM— The EPA's Analysis Is the Lowest Value for Gas Capture Rates.

FACT: EPA's analysis cannot be used for even supporting an average 75% capture rate, nonetheless a minimum of 75%.

In this period of time, EPA's assumed average 75% capture rate had come into doubt because it was predicated on patently incorrect definitions that resulted in dramatically overstating collection efficiency. Possibly in an effort to offset those concerns, SCS first, without any basis, attempts to redefine EPA's value as the lower end of a range of reasonableness upon which its claimed improvements should be added.

SCS does this by claiming (at p. 1-2) that a memorandum prepared in 2002 for EPA by Chad Leatherwood of the Eastern Research Group,¹ which is often used as the factual basis for an assumed 75% capture rate, sets a baseline minimum value for collection efficiency of a range extending upwards to 99%, was the minimum, because it was based on old data –

“Most of the published sources cited by the memorandum are at least 15 years old. Consequently, these sources do not reflect LFG system operational experience after implementation of USEPA's New Source Performance Standards (NSPS; 40 CFR Part 60, Subpart WWW).”

¹

Memorandum to Brian Guzzone, EPA, from Chad Leatherwood, Eastern Research Group, Inc., dated November 18, 2002, re: Review of Available Data and Industry Contacts Regarding Landfill Gas Collection Efficiency (Leatherwood Memo), at p. 1.

But, this line of argument has no factual basis.

For one thing, the Leatherwood purported – incorrectly – that 60%, not 75%, was the minimum value capture rate. For another, even if more recent data did establish that capture rates have increased – although, in fact, the reverse is the case – the 75% value in the misconstrued Leatherwood memorandum cannot serve as the base upon which to add those gains to.

Because the memorandum’s author uses demonstrated selection bias and misstates the position of key stakeholders, the Leatherwood memorandum and those that followed cannot be used to support anything, nonetheless being transmuted from an average to a minimum value. For these reasons, 75% is not in any manner, shape or form a minimum estimate for gas capture rates.

Selection Bias. The Leatherwood memorandum states that it has done a literature search. However, among the several reported studies with low capture rate values, ERG’s search omitted one of the major works on the environmental impacts of landfills. It was authored by Procter & Gamble scientist, Peter White, and which we have previously provided to EPA.² According to the P&G study, which actually did a dispassionate literature review, 40% is the appropriate capture rate while operating:

“Estimates of [gas] collection efficiencies vary, 20-25% (De Baere et al., 1987); 40% (RCEP, 1993); 40-70% (Carra and Cossu, 1990); 40-90% (Augenstein and Pacey, 1991), and will depend on size, shape and engineering design of the landfill site.”

After reviewing each of the studies, the P&G scientists decided that “[f]or the purposes of the L[ife] C[ycle] I[nventory] model, a figure of 40% will be assumed.”³

Forty percent has also been a widely applied for the average instantaneous capture rate used in Europe.⁴ Israel appears to use 50%.⁵ Our interviews with solid waste managers in the United States generally suggest collection efficiency in the similar 50% range, as well.⁶ (The Intergovernmental Panel on Climate Change’s (IPCC) 20% capture rate estimate on an average lifetime basis was not made until 2007,⁷ several years after Leatherwood’s 2002 putative literature search.)

² Peter White, *Integrated Solid Waste Management: A Lifecycle Inventory* (Aspen Pub. 1999), at p. 275.

³ *Id.*, at pp. 283-284.

⁴ 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.

⁵ 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. See, also, Riitta Pipatti and Margareta Wiherasaari, “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%]; and Hans Williamson, “Production and Use of Landfill Gas: Energy Recovery,” Paper for International Conference on Solid Waste Management & Technology (Lisbon, October 1997) [25% - 50%].

⁶ Interview with Reg Renaud, April 10, 2002.

⁷ IPCC, *Fourth Assessment Report*, at p. 600.

However the survey is done, there is something highly questionable when the lower boundary of the range of experience is reported as 60% at the same time there is so much in the literature pointing to 20% as the low value and 40% as an average value.⁸ Also, it is critical to note that these are assumptions about *instantaneous* rates (i.e. only when gas collection is installed and functioning), not *integrated* rates (i.e. over the lifetime of landfill gas emissions, which extends for more than half of the time on a weighted basis that gas is generated and there is no functioning gas collection system).

Essentially, as well as ignoring the times when there is no functioning collection system, EPA is actually discussing assumptions about what landfills “should achieve,” not how they actually perform when systems are installed and functional.

Distorted Summation. The Leatherwood Memorandum, which has also been referenced by CARB, concludes its survey essentially restating EPA’s earlier protocols for calculations of air emissions from a variety of industries, including landfills, and known as the “AP-42 report” (although the memorandum’s author concedes he was unable to locate the documents on which the AP-42 rested):¹⁰

“Overall, the ranges provided in *AP-42* seem to correlate with current conventional wisdom of collection efficiency at landfills without a geomembrane component in the cover, where *AP-42* reports collection efficiencies of 60 to 85 percent, with an average of 75 percent.¹¹

In fact, even with all of the selection biases built into the ERG survey, still there were other opinions proffered that belied the 75% claim. For whatever reason, however, they were simply ignored in Mr. Leatherwood’s summation of the survey responses. He then compounded that additional bias by taking the higher range that bias created and incorrectly calculated an even higher average from it.

For example, GSF Energy was reported as having stated that one facility operator “estimated that *a well-designed system* can typically collect *about 50 to 60 percent of the gas* generated within a landfill,”¹² but just disappeared from Mr. Leatherwood’s range.

In summary, apart from its preamble that acknowledges the lack of any reliable factual data from which to reach any conclusion, the Leatherwood memorandum has no probative value for anything, nonetheless using 75% as the floor value for an assumption about gas collection efficiency.

⁸ Leatherwood Memorandum, at p. 10.

⁹ Leatherwood Memorandum, at p. 2.

¹⁰ U.S.E.P.A., *Compilation of Air Pollutant Emission Factors* (AP-42)(Fifth Edition 1998), at p. 2-4.

¹¹ *Id.*, at p. 5.

¹² Leatherwood Memorandum, at p. 5 (emphasis added).

SCS's SECOND CLAIM–

The NSPS Standards Required Higher Gas Collection Performance

FACT: EPA's new sources contain no substantive requirements other than to have some piping installed for a limited period of time, and also the private sector has recently exploited this to substantially weaken prior industry practice over the past five to ten years.

Not only does the Leatherwood memorandum fail to define a lower bound estimate for collection efficiency, as SCS argues, neither does the NSPS rule it points to provide any reason why more recent performance is any better.

In 1996, EPA promulgated the Landfill Air Rule to comply with the Clean Air Act Amendments of 1990, which imposed the first air emission standards for landfills unrelated to subsurface gas migration into adjoining structures.¹³ SCS's second claim at pp. 4-5 is that gas collection systems required by that rule today perform significantly better than earlier landfills which, in order to prevent cover blow outs, had gas collection systems before the rule:

“By December 1998 [after the NSPS rules took effect], higher efficiencies were necessary for NSPS Subpart WWW compliance.” (at p. 2)

In fact, EPA's Landfill Air Rule did nothing of the kind. It deleted the prescriptive standards in the original proposed rule, and substituted unenforceable performance standards in its place. The result is that all that was required in very large landfills after 1998, when the rule took effect, was that some undefined number of vertical gas collection wells be installed five years after waste emplacement. Thus, all that the 1996 NSPS standard did was codify what was in common practice by large landfills in order to prevent escaping gas from damaging the geomembrane cover. It did not require anything substantively more.

¹³

40 C.F.R. Part 60 Subpart WWW.

The final Landfill Air Rule weakened the original proposed rule's threshold of coverage by 40%.¹⁴ In addition to exempting from the regulations 95% of the landfills and 61% of the methane emitted by landfills,¹⁵ the final Landfill Air Rule explicitly acknowledges that it deleted the specific specifications in the proposed rule for what an active gas collection system should consist of in order to "streamline and increase flexibility."¹⁶ EPA added that 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."¹⁷ Following this policy, the rule states that "a wide variety of system designs are possible"¹⁸ so long as the system "collects gas at a *sufficient rate*".¹⁹

But, no definition of "sufficient" is included, and, therefore, the rule makes no demand on landfills to collect 75% (or any particular percent) of the gases it generates. All else that remained in the final rule were a few other similarly undefined requirements for a professional engineer,²⁰

¹⁴

56 FEDERAL REGISTER 24494 (May 30, 1991). At the same, the final rule made the emission rate cutoff lower, 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):

$$M_{NMOC} = \sum 2kLM(e^{-kL})(C_{NMOC})(3.6 \times 10^{-6})$$

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In the end, the final rule effectively limited its reach to those very large landfills in which the buildup of gas pressure under a geomembrane would be so great as to bulge or blow out the cover absent an active system for extracting that gas to relieve the pressure. Otherwise there would be no reason to set such high thresholds for coverage: Europe's requirements for landfills to install gas collection systems did not contain any such exclusion for most landfills.

¹⁵

61 FEDERAL REGISTER 9914 and 9916 (March 12, 1996).

¹⁶

61 FEDERAL REGISTER 9907 (March 12, 1996).

¹⁷

61 FEDERAL REGISTER 9911 (March 12, 1996).

¹⁸

40 C.F.R. §60.752(b)(2)(i)(D).

¹⁹

40 C.F.R. §60.752(b)(2)(ii)(A)(3).

²⁰

40 C.F.R. §60.752(b)(2)(i).

adequate capacity,²¹ sufficient density,²² a sufficient extraction rate²³ and minimized lateral migration,²⁴ none of which have any enforceable meaning.

Therefore, on its face, the existence of the rule cannot serve as the basis for claiming that NSPS created substantive requirements for higher performing gas collection systems. As to those things that might require better operation, the rule was silent. These known factors include a minimum density of vertical collection wells, or the use of horizontal pipes in the open working cells, or in quickly, and not never, installing a low permeable, geomembrane cover, which is essential for the systems to function properly, or, most critically, not recovering energy, which works directly at cross-purposes with optimization of gas capture.²⁵

Parenthetically, since the rule's promulgation, there has not been any of that innovation improving collection performance, which the rule purported to encourage. Instead, the private sector has exploited the rule's "flexibility" to sacrifice efficiency in order to enhance corporate earnings. Three examples are reduced well densities, delays in installation of the final cover and recirculation of leachate.

Well Density. The density of wells, which represents how far from the other each of the vertical pipes is drilled into the landfill, has decreased from approximately every 150 feet when gas collection was first developed to 350 feet today. This has not happened because there is any evidence that emissions can be eliminated with less than half the wells: obviously, it cannot. Instead, as to odors and subsurface migration into adjoining structures, which are the only two widely observed effects from more uncontrolled emissions, alternatives means to prevent them have evolved that do nothing to reduce GHG releases. As regards odors, more sophisticated perfumed misting has disguised the odors, and larger buffers downwind have reduced affected populations. Concerning explosions, the introduction of low permeable geomembrane liners on the sides, which was required by the earlier Landfill Groundwater Rule (also referred to as the "Subtitle D" rules),²⁶ has blocked subsurface gas migration.

²¹ 40 C.F.R. §60.752(b)(2)(ii)(A)(1).

²² 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).

²³ 40 C.F.R. §60.752(b)(2)(ii)(A)(2); §60.751 and §60.751.

²⁴ 40 C.F.R. §60.752(b)(2)(ii)(A)(4).

²⁵ This latter point is not commonly recognized outside the industry, but is well understood by practitioners, as is acknowledged in the SCS paper, at page 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."

The reason why gas collection efficiency is degraded by landfill-gas-to-energy (LFGTE) is because landfills that only flare and properly minimize gas and moisture in their landfills will be able to pull gas harder through the gas collection pipes than facilities that recover energy. This is because increased vacuum forces tend to draw more oxygen from the surface into the collection wells along with gas from the surrounding wastes. The limiting condition for oxygen infiltration by landfills that flare is <5%, because more creates combustive conditions. That is 50 times greater than can be tolerated at landfills that recover energy, which is <0.1%, because the methanogenic microbes that generate methane cannot survive in the presence of all but the slightest trace concentrations of oxygen.

²⁶ 40 C.F.R. Part 258.

Delays in Final Cover. Also, installation of low permeable final covers have been delayed for years, even though these are absolutely essential for functioning gas extraction systems, as even SCS acknowledges.²⁷ This has been done largely in order to increase moisture intrusions, which accelerates decomposition, and recovers air space so that the same volume can be resold a second time, further increasing profitability.

Leachate Recirculation. In tandem with delays in capping closed cells to recover airspace, leachate has been recirculated, and sometimes outside liquids added, causing rapid differential settlement of the waste mass. That forces ineffective flexible horizontal tubes, subject to flooding and collapses, to be substituted for the standard rigid vertical wells that otherwise would tilt and snap.

SCS's THIRD CLAIM –

The sniff test provides a basis to claim 99% collection efficiency

FACT: The protocols in the sniff test were designed for an earlier landfill design that has no applicability to current standards, and is incapable of detecting uncontrolled emissions.

SCS claims at page 9 that the so-called “sniff test” in the Landfill Air Rule provides a basis to determine if a landfill is not achieving collection efficiency rates of 99%. Only if a landfill exceeds the limits in the test (or has the gas collection system operated for other conflicting purposes, such as LFGTE) is the site considered to exhibit the lower end of SCS’s proposed capture rate ranges. Otherwise it is considered to exhibit the high end of the proffered ranges up to 99%.

Of the 17,223 words in the Landfill Air Rule, this test is the only section that purports to provide a measure of system performance. It is a requirement that the surface concentration of methane not exceed 500 parts per million (ppm). The measurement is to be taken quarterly, every 98 feet along the perimeter of the landfill and in a serpentine pattern across the collection area during typical weather conditions.²⁸

In fact, as discussed below, the 500 ppm standard was never validated for anything but odor control, and was not designed for the conditions at a modern landfills where it has no realistic probability of detection, is easily gamed, and has an escape hatch that excludes the major area of concern.

²⁷

SCS Report, at p. 9:

“The type of cover is directly related to the collection efficiency of the LFG collection system in terms of permeability of the soil or synthetic layer. Thick final clay covers that are compacted obviously have a lower permeability and are more resistant to diffusion of gas (or infusion of air) through the cover than a daily cover soil with a much smaller thickness. Furthermore, plastic liners can basically block all diffusion to the atmosphere, thus resulting in the opportunity for the highest collection efficiencies.”

²⁸

40 C.F.R. §60.753(d) and §60.755(c). There is another performance standard in the Landfill Air Rule, but that does not deal with the *collection* part of the system, which specifies how gas is to be extracted. Rather it deals with the *control* part of the rule in which the efficiency of the flare, which deusters the collected gas, is required to be 98% efficient. 40 C.F.R. §752(b)(2)(iii)(B).

There Is No Scientific Basis for 500 ppm Beyond Odor Control. There is no established relationship between the 500 ppm concentration limit and anything other than odor control. Nothing has ever been asserted to claim that 500 ppm bears any relationship to any specific capture rate, nonetheless to public health and welfare or in regard to global climate. Rather, as a review of the record demonstrates, the rule is little more than an operational standard intended to define what was thought to be good practices in 1985 for odor control only when using design standards then in common practice, and also when the test is not gamed by the operator.

Back in 1991, the initial proposed Landfill Air Rule had not contained any provision attempting to restrict surface concentrations of methane. It did, however, state the EPA was aware that the South Coast Air Quality Management District (SCAQMD) in California, where the first landfill gas management local rule had been promulgated in 1985, had set such a limit as part of its regulatory scheme. At that time in 1991, EPA rejected the monitoring standard “due to the uncertain concentration at which additional wells would be warranted, adding, as well, that “this method may not detect the lateral migration of the landfill gas.”²⁹

Yet, in the final rule in 1996, EPA changed its mind and incorporated the SCAQMD’s 500 ppm standard. EPA’s Federal Register notice provided no explanation for the agency’s new found acceptance for the new 500 ppm methane standard other than noting: “[n]umerous commenters asserted that the proposed rules did not address surface methane emissions resulting from insufficient well spacing or from breaks in the cover material.

“The commenters recommended that monitoring of surface emissions be required to ensure the proper operation of collection system equipment. Upon further analysis, the EPA decided to require surface emission monitoring and the maintenance of negative pressure at all wells, to ensure proper collection system design and operation.”³⁰

In discussions, EPA has amplified on the Federal Register notice, indicating that the 500 ppm standard was intended to be a last minute performance standard to substitute for the deletion of many of the prescription design standards in the proposed rule.³¹

SCAQMD’s files from 18 years ago that we recovered from storage provide somewhat more details about what the 500 ppm standard actually was intended to accomplish. Apparently, the local rule was precipitated by passage through one house of a bill by Assemblyman Calderon that would have required extensive gas control at landfills. The 500 ppm maximum concentration level was set at the point that testing of 14 area landfills indicated was necessary “to prevent an odor nuisance caused by a ‘hot spot’.

“Generally ‘hot spots’ occur on the working face of the landfill where cracks develop at the thin soil over the refuse. To prevent cracks from developing,

²⁹ 56 FEDERAL REGISTER 24492 (May 30, 1991).

³⁰ 61 FEDERAL REGISTER 9912 (March 12, 1996). The preamble to the rule contains no citation to references in support of 500 ppm, as is typically done when there is a factual underpinning to a provision in a rule. Also, for whatever reason, the BID for the final rule contains no such reference to commenters or other explanation to provide a basis for its action. E.P.A. *Air Emissions from Municipal Solid Waste Landfills*, at p. 2-87 to 2-89.

³¹ Interview with Martha Smith (US EPA OAR), July 8, 2002.

proper maintenance procedures have to be observed. Especially at the working face. Measuring the limit as methane allows the use of already available portable testing equipment to get instantaneous results.”³²

None of the factual background for the local rule purported to relate 500 ppm to any capture rate. Five hundred parts per million is essentially an operational standard – like the maintenance of negative pressure and oxygen/nitrogen infiltration provisions – intended to approximate what a well-managed gas system in landfills with clay-only covers ought to be able to achieve.

The Sniff Test Is Vanishingly Unlikely to Detect Emissions. The type of monitoring protocol in the air rule, in which flux boxes are placed at approximate 100 feet intervals in a grid can only produce reliable results if the emissions are diffused across the surface of the landfill within reasonably defined variability, which is not the case for capped landfill cells. Consequently, the required monitoring will be unlikely to detect problems, except by chance, even if undertaken without purposeful intent to manipulate the results.

Between the 1980s (when the local rule was developed in California upon which the 500 ppm standard was later patterned) and the 1990s, when EPA adopted its rule, there was a key change in design standards for liners and covers in federal and state regulations. A low-permeable $\frac{1}{16}$ " plastic sheet was generally added to the clay liner system on the top, sides and bottom of the landfill.³³

Other than the very minor amounts of gas that may diffuse through the low permeable cover layers (and even then, only if there are no imperfections in the geomembrane creating easier paths of escape), where there are no breaks or tears in a plastic liner, the gases that are not captured by extraction wells will not be able to move out into the atmosphere. Instead, a part of the gases will move laterally out the bottom sides or through the gravel bed surrounding the leachate collection system into adjoining properties where they will not be picked up by this protocol. This is a criticism that EPA itself made in 1991 when it initially declined to include the California local rule in its draft.³⁴

Where there are breaks in the plastic liner, as is often the case, major volumes of gas will escape in localized “hot spots,” which are readily identifiable by brown or dead vegetation in the area.³⁵ Because hot spots are unlikely to intersect with those equally spaced far apart detection

³² 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), at pp. 5-6.

³³ 40 C.F.R. §258.40(b). The proposed groundwater rule in 1988 (53 FEDERAL REGISTER 33352 (August 30, 1988)) had not required a composite liner that included a 30-60 mill flexible membrane liner in addition to 2-feet of compacted clay, as did the final rule. 40 C.F.R. §258.40(b). The general standard at the time in the 1980s when the 500 ppm test was developed had been a single compacted clay liner with a hydraulic conductivity of less than 1×10^{-7} cm/sec, and which had not included a synthetic geomembrane. Technically, the actual language in the rule that prescribed the final cover standard did not directly require a plastic layer. Instead, it only required that the permeability of the cover not be less than that of the bottom liner. Subsequently, alternative daily covers made of sodium bentonite, especially for the clay component of the cover, has began to be used, U.S.E.P.A., *Geosynthetic Clay Liners Used in Municipal Solid Waste Landfills* (EPA530-F-97-002)(Revised December 2001), although plastic liners continue in common.

³⁴ 56 FEDERAL REGISTER 24492 (May 30, 1991).

³⁵ AEA Technology, *Methane emissions from UK landfills* (UK Department of the Environment, Transport and the Regions)(1999), at p. 2-9.

devices, that will only succeed in identifying proportionately the same degree of escaping methane across the entire working face if the releases are diffused fairly equally across that face. Otherwise, the results from the sample would only reflect the whole by chance. That would happen only a vanishingly small percent of the time.

In statistics, the Poisson distribution is used to compute the probability of such things as the EPA methodology in locating even one hot spot, never mind all of them. Poisson describes a process where the probability of an event is very small relative to the size of any reasonable sample. It is typically used to estimate probabilities of such rare events as clusters of rare diseases.³⁶

The following table shows the probability of even one hot spot being detected as a function of the number of hot spots that might exist at a 100-acre landfill, as well as all of them.³⁷

³⁶ Harnet Murphy, *Statistical Analysis for Business and Economics* (3rd Ed.) (Addison Wesley Publishing Co., 1985), at p. 231. The assumptions used are as follows: a 100 acre landfill, with dimensions of approximately 1500' x 3000', with 364 equally spaced detection units when spread at 100' intervals along the perimeter and across the working face in a grid (the effect of sloped sides are ignored). The number of hot spots, which are assumed to be 6" by ¼", are a variable, and the detection limits are 6" x 6". The formula for the Poisson distribution is:

$$p(x; m) = ((e^{-m}) \times (m^x)) / x!,$$

where p is the probability and m is the intensity

³⁷ Based on statistical consultation with Eric Rambo (PA Consulting).

Probability of Detecting Hot Spots At 100 Acre Landfill Using EPA Monitoring Protocols		
# Hot Spots	Probability of Detecting 1 Hot Spot	Probability of Detecting All Hots Spots
1	0.0042%	0.000782788725175
2	0.0104%	0.000000306619000
3	0.0146%	0.000000000080069
4	0.0209%	0.00000000000000016
5	0.0251%	2.4569800000e-18
6	0.0313%	3.2080100000e-22
7	0.0355%	3.5902300000e-26
8	0.0418%	3.5157500000e-30
9	0.0459%	3.0602700000e-34
10	0.0522%	2.3974227905e-38
20	0.1044%	3.1133700000e-81
30	0.1566%	2.486200000e-126
40	0.2087%	7.037300000e-173
50	0.2608%	1.643700000e-220

SOURCE: Center for a Competitive Waste Industry

Thus, as an example, if there were one hot spot per acre, and 10 across a 100 acre landfill, the probability of detecting just one of those 10 hot spots in a year using EPA's protocols would be 0.0522%, or one in 2,000. That is equivalent to the likelihood of the average person dying in the next year from being hit by a car.³⁸ The probability of detecting all 10 of them would be 2.4×10^{-38} , which is a decimal point followed by 38 zeros and then 2.

Essentially, statistics tells us that the current protocols are useless for detecting methane concentrations once the geomembrane is laid down. And that is assuming that the operator does not seek to game the system, something which, as discussed below, is exceedingly easy to do.

The 500 ppm Standard Can Be Easily Manipulated. The 500 ppm standard has no technical basis relating that level of methane concentration at the landfills perimeter to protection of health, welfare and the environment, as well as to explosion control. But, even if it did, the particular monitoring protocols in the rule are so easily manipulated as to thoroughly undermine the rule's effectiveness.³⁹

At the same time, there may be innate constraints on the practical ability to exploit the system that ought to be acknowledged. Breaks in the cover geomembrane, which cause hot spots, are not only a source of uncontrolled emissions, but also, especially during periods of high barometric pressure and low gas buildup, of air infiltration into the waste mass. Air ingress both

³⁸ Les Vertesi, "Risk Assessment Stratification Protocol," *Canadian Journal of Emergency Medicine* (January 2003), at p. 3 TABLE 1.

³⁹ 40 C.F.R. §60.755(c).

creates a fire potential in the landfill and also degrades methane formation, a matter of concern for those landfills with gas collection and energy recovery.

Among the ways that the results of monitoring can be manipulated are as follows:

- The results are easily manipulated by taking measurements when there is high barometric pressure.
- Hot spots can be readily avoided by not placing detection units near brown or burnt vegetation.
- The rule permits so many re-tests in the event a prior test were to show an exceedance that it would be nearly impossible to fail.

The 500 ppm section of the air rule only requires that the landfill's perimeter be monitored for surface concentration of methane "on a quarterly basis".⁴⁰ That is to say, monitoring is to be done once each season on any one of the 90 days determined by the operator.

Requiring four-season monitoring would seem like a good thing. However, except in extremely cold climates, the effect of temperature on gas generation and emissions is largely confined to the upper lift, and ambient temperatures have less impact at depth. However, other factors not directly related to temperature per se will have decisive effects on the rate of gas emissions.⁴¹

Specifically, surface measurements of methane or other landfill gases also vary with low barometric pressure, high wind velocity and droughts that dry out and crack clay. Wind velocity is compensated for by use of a measuring device that is dug into the surface, but the barometric pressure and humidity largely remain as uncontrolled variables.

Moreover, concentration levels can even vary in much subtler ways. As an example, high barometric pressure does not reduce the volume of gas generated, but rather it suppresses the amount that is released during its course. For that reason, the greatest variation has been found not due to the largest absolute pressure drop to low barometric conditions. Instead, the greatest methane fluxes have occurred as a function of how long and intense the prior period of high barometric pressure extended. For that leaves a large backlog ready to surge out when the pressure drops, an effect that is more pronounced the greater the gradient. Indeed, in several recorded cases, this particular barometric-duration effect was so pronounced as to have caused explosions in nearby properties.⁴²

All this creates the potential to manipulate the test results by moving the date and times expected to generate low gas-release conditions. Presumably, EPA may have intended to discourage the potential for teasing test results with a subsequent admonition that "[m]onitoring shall be performed during typical meteorological conditions."⁴³ However, without a definition for

⁴⁰ 40 C.R.F. §60.755(c)(1).

⁴¹ William Robinson, *The Solid Waste Handbook: A Practical Guide* (John Wiley & Sons, 1986), at p. 316.

⁴² AEA Technology, *Methane emissions from UK landfills* (UK Department of the Environment, Transport and the Regions, 1999), at p. 2-9.

⁴³ 40 C.F.R. §60.755(c)(3).

the word “typical,” and with the intricate subtleties affecting what “typical” might mean, no obvious practical constraint appears to have been placed on landfill owners to prevent abuse. In any event, the reports of methane monitoring sent to the states and the Regional EPA offices do not contain any information that even purports to describe what the weather conditions were on the day the samples were taken, and certainly not any representation as to whether those conditions were “typical.”

Sampling is Not Required in the One Place Emissions are a Problem. The only possible problem in meeting the standard would have been on the working face or at sites where the operator is keeping open a cell beyond the time it takes to reach grade in order to recover air space through settlement and decomposition. Without a final composite cover, including a geomembrane, certainly there will be difficulty meeting 500 ppm in those cases.

However, the waste industry succeeded in adding a seemingly innocuous technical provision to the final rule that has the effect of avoiding sampling of these uncovered cells:

“Areas with steep slopes or other dangerous areas may be excluded from the surface testing.”⁴⁴

The working faces of open cells or cells that have reached grade but have not yet been capped have been widely described by operators as “dangerous” in order to avoid monitoring.⁴⁵ Consequently, the one place where one would expect to detect emissions with this procedure is excluded from the sample.

For all these reasons, the sniff test provides no indicia of actual gas collection performance in modern landfills.

SCS’s FOURTH CLAIM– Substantially more than 10% of methane is oxidized

FACT: The oxidation phenomenon was qualified for earlier landfills designs and, with one insignificant exception, has no application to current standards.

SCS claims at p. 14 that not only is methane oxidized in the dirt layer overlying landfills, but oxidation accounts for substantially more than the 10% rate assumed by EPA. However, the technical studies on which the oxidation theory is based make clear that the process does not pertain to modern landfills.

EPA propounded the oxidation theory on a study by Czepiel, which found in field and laboratory studies during 1994 that 10% of the methane generated in a landfill with a clay cover was oxidized in the cover soil over the course of a year.⁴⁶

⁴⁴ 40 C.F.R. §60.753(d).

⁴⁵ Interview with Dennis Mack (WI DNR SW, Chief Landfill Unit), August 22, 2003.

⁴⁶ P. M. Czepiel, et al., “Quantifying the effect of oxidation on landfill methane emissions,” *Journal of Geophysical Research* (July, 20, 1996), at p. 16,720-1. See, also, David Kightley, et al, “Capacity for Methane Oxidation in Landfill Cover Soils Measured in Laboratory-Scale Soil Microorganisms,” 61 *Applied and Environmental Microbiology* 592 (February 1995). Alex de Visscher, et al, “Methane Oxidation in Simulated Landfill Cover Soil Environments,” 33 *Environmental Science & Technology* 1854 (1999).

When the gases that are emitted are diffused throughout the overlying soil blanket, as would have been the case with most landfills constructed before 1991, this study might continue to have vitality. But, after a landfill cell is closed, Subtitle D landfills gases are not diffused at the surface throughout that earthen layer, because, since 1991 a composite cap has been required under that soil blanket, including in practice a 60-mil (or $\frac{1}{16}$ ") high density polyethylene plastic membrane that effectively impedes the passage of gases from the waste into that cover soil.⁴⁷

This is key. It means that instead of the methane diffusing throughout the topsoil for maximum oxidizing effect, the gases that are released above the landfill with a composite cover are concentrated in high fluxes at a handful of cracks and tears in the plastic sheet. Concentrated high flux emissions quickly overwhelm the capacity of the topsoil to oxidize the escaping methane through these hot spots.⁴⁸

Czepiel expressly stated that not only was his study not done at a landfill with a synthetic geomembrane, but also, “[p]eriodic maintenance of the cover materials has minimized significant surface cracks” in the clay layer, as well.⁴⁹ That is to say, nothing in his study can be used to describe what happens to the methane that flashes through a small number of hot spots on the top face of the landfill.

He further reemphasized again in his conclusion that his findings did not apply when gases are released in high fluxes through narrow cracks:

“Waste settlement, surface erosion and soil desiccation often promote significant surface cracking, providing paths of minimal resistance to gas flow, effectively bypassing microbial influence. Our study generally lacked surface cracks, although this characteristic may not be representative of the entire spectrum of landfill surfaces.”⁵⁰

Furthermore, a consultant for the U.K. Department on the Environmental conducted a comprehensive study involving 250 measurements at a landfill with a composite cover and found that there was no oxidation effect:

“Methane oxidation is only observed where the diffusion gradient through the cap is very small, and therefore the methane oxidizing bacteria can cope with the rate of supply of gas. When higher fluxes predominate there is little evidence either for or against methane oxidation being a significant component of emission control.”⁵¹

⁴⁷ 40 C.F.R. §258.60(a)(1). Technically, the rule only requires that the permeability of the cover not be less than the bottom liner, although in practice this has been met with a composite system in the cover as well. While the industry today is now attempting to advance bio-covers as an alternative to composite covers, the absence of a geomembrane would make it impossible to have functioning active gas collection with profound implications for global warming.

⁴⁸ Czepiel, *supra*, at p. 16,727. Oxidation was observed to follow the Arrhenius relationship, or parabolic behavior, in which oxidation increases with greater inputs, but only to a distinct maximum, after which it rapidly declines.

⁴⁹ Czepiel, *supra*, at p. 16,721.

⁵⁰ Czepiel, *supra*, at p. 16,728.

⁵¹ AEA Technology, *Methane emissions from UK landfills* (UK Department of the Environment, Transport and the Regions, 1999), at p. 2-9.

A similar field examination by researchers at a Swedish landfill corroborated the U.K. findings.⁵²

We are at a loss to understand how EPA and the landfill industry can continue to contend could that oxidation provides either 10% or more augmentation in collection efficiency when the underlying study specifically states that it is not applicable to landfills with composite covers, and EPA's rules have effectively required composite covers for more than 10 years.

At the same time, for the period of time between the use of daily 6 inches of dirt or alternative cover on the working face of an open cell, and the later installation of the final composite cover when a 12 inch dirt intermediate cover is laid down pending installation of the final cover, conditions do exist for some oxidation to occur.

How much decay can be relied upon in this narrow window of time under real world conditions is another matter. Carefully read, SCS makes no representation about what is actually achieved, but rather what ideally, "can" be achieved (at p. 19). In doing so, SCS attempts to sidestep the key question of what is actually realized in practice – even in the very attenuated period of time that any oxidation at all can appropriately be claimed.

When the limited time oxidation is considered under typical conditions, there is little basis to conclude that oxidation effects are sufficient to warrant consideration.⁵³

SCS's FIFTH CLAIM – Landfills sequester 2½ times CARB's estimates

FACT: While some sequestration theoretically may occur, there is currently no valid data to use to make any reliable estimate of its extent.

SCS claims that, by interring lignin containing brush and wood, 2½ times more carbon is sequestered in a landfill than CARB recognizes (at p. 26).

The concept of lignin sequestration is valid in theory. Essentially, the lignin in woody plants, which provides support for twigs and branches, can significantly retard decomposition of the organic material it encapsulates. However, the extent to which the organic fraction of wastes in a landfill are affected by lignin is unknown. As to the one study attempting to quantify it by Morton Barlaz,⁵⁴ EPA itself disclaims reliance on such single study:

"Perhaps the most important caveat to the analysis of GHG emissions and sequestration associated with landfilling is that it is based on a single set of laboratory experiments, those conducted by Dr. Morton Barlaz. While researchers

⁵² 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," *Journal on Environmental Quality*, at p. 1182.

⁵³ If a hypothetical 10% value is used as a place holder for average oxidation when it actually occurs, that figure only pertains to oxidation of the fraction of total gas generation not captured by the gas collection system. Thus, if capture rates are generously assumed to be 50% during the time gas collection is functioning, oxidation would achieve an additional 0.5 percentage points ($50\% \times 10\%$). That 0.5 percentage points, in turn, would only pertain to the very small fraction of the total time that gas is generated. If, to illustrate the impact, the relevant time frame when oxidation occurs was 10% of total gas generation on a weighted basis, the net impact of oxidation would be 0.05 percentage points ($0.5\% \times 10\%$).

⁵⁴ Morton Barlaz, "Biodegradative Analysis of Municipal solid Waste in Laboratory-Scale Landfills," (EPA600/R-97-071, 1997).

other than Dr. Barlaz have conducted laboratory studies that track the degradation of mixed MSW, his experiments were the only ones we identified that rigorously tested materials on an individual basis. Dr. Barlaz is recognized as an expert on the degradation of different fractions of MSW under anaerobic conditions, and his findings with respect to the methane potential of mixed MSW are within the range used by landfill gas developers. Nevertheless, given the sensitivity of the landfill results to estimated methane generation and carbon sequestration, we recognize that more research is needed in this area.⁵⁵

But, that is just the beginning of the problems infecting any study attempting to quantify the lignin effect in landfills. The raw outputs of Dr. Barlaz's study did not add up, and he was forced to rely upon subjective adjustments of that data to draw his conclusions.

Dr. Barlaz is engaged in substantial remunerated consulting work for landfill companies and the organizations that they fund. To confer reliance for such a significant issue on anyone's single study is, as EPA states, improper. To do so from this source where appearances of conflicts of interest exist can only raise further questions – questions that are compounded by the weak study results that were subjected to several adjustments.

Some value may be appropriate for carbon sequestration in a landfill, but, at present, no data exists to support any particular estimate, and certainly not the one suggested by SCS, for which they do not even provide the connecting data.

SCS'S SIXTH CLAIM

Industry studies show very high capture rates

FACT: The studies that SCS relies upon to demonstrate very high capture rates use both the wrong definitions and an invalid methodology.

SCS puts forward a number of studies, at pp. 14-15, largely based on mass balance analyses, that it claims show landfills with exceedingly high capture rates up to and including 100% – something which is quite a challenge inasmuch as there is no functioning gas collection system for half or more of the time that gas is generated:

“Spokas, et al. (2006) summarized intensive field studies of the methane mass balance for nine individual landfill cells at three French landfills with well-defined waste inputs. The collection efficiency was calculated as the ratio of recovered gas to empirically modeled gas generation. Efficiencies between 88 and 98% were calculated for sites with completed clay covers similar to those widely used in North America. The study reported direct measurements of collection and emissions, the sum of which, in the absence of any storage changes, is the generation. Recalculating collection efficiency by substituting the sum of collection and emission for modeled generation indicates that the final clay covers performed uniformly well [Montreuil-sur-Barse – 93%, Lapouyade – 93% (summer) and 99% (winter); and Grand'landes – 100%].”

These mass balance analyses use both the wrong definition to address the question and an invalid protocol to do the analysis.

⁵⁵

EPA, *Greenhouse Gas Emissions from Management of Selected Materials in Municipal Solid Waste* (EPA530-R-96-013, 1998), at p. 102.

Wrong Definition. Before turning to the question of whether mass balance analyses has any value in estimating landfill capture rates, first there are the problems with any approach that only considers performance during a short slice at time at those landfills that volunteer for testing. See the detailed discussion of the appropriate definitions to use for assessing gas collection performance set forth in APPENDIX A.

Essentially, even if for the sake of argument there was value in this sort of approach, it only purports to examine collection performance during the time when the landfill is closed and covered, and also prior to the time that the gas systems are withdrawn from service⁵⁶ and postclosure maintenance ends.⁵⁷ The end of postclosure maintenance begins the time, as EPA itself has conceded, when the barriers including the final cover “ultimately fail.”⁵⁸ That permits rainfall to re-enter the site. This reignites a second wave of gas generation in future decades’ hence when there is no gas collection, as the CIWMB staff has pointed out,⁵⁹ just as there is none in the first several years of a landfill’s life.⁶⁰ That is to say, the time when SCS’s leading studies examine is the singular time when gas generation is at its lowest, and, because the entire site is finally covered, gas collection is at its highest point.

Most critically, this narrow window in time ignores the entire period before and afterwards when almost all of the gas generation occurs, without any gas collection or with collection efficiency compromised. Also, since the studies only look at landfills whose owners volunteer to be examined, presumably only the best, not the average and worse, landfills are reviewed. Finally, it ignores the fact that the majority of major U.S. landfills have de facto recently shifted from the dry cell operational practices contemplated in Subtitle D, to wet cell operation, with all of its implications for degraded collection efficiency, which is ignored in these studies.

For these reasons, any statement that speaks only to the best systems during the short period of time when gas collection is optimized (ignoring all of the time there is no collection or collection is compromised) is, *per se*, invalid. It is obvious that aggregate GHG emissions are actually a function of what the average systems achieve over the entire time that they generate methane.

Mass Balance Analysis Invalid. To return to the protocols used in these studies, in one form or another they work from the quantity of gas that is captured, but have to find some way to account for the amount that escapes, either from the top, sides or bottom of the landfill extending over, in the case of megafills that receive most wastes today, hundreds of acres. Then they calculate collection efficiency as the amount captured (which can be known in some cases) divided by how much is generated (which is not known).

To approximate the volumes that escape, they select from among a wide range of studies that purport to predict how much total gas is generated, that typically vary all over the map but

⁵⁶ 40 C.F.R. §60.752(b)(2)(v)(C).

⁵⁷ 40 C.F.R. §258.61(a).

⁵⁸ 53 FEDERAL REGISTER. 168, at pp. 33344-33345 (August 30, 1988). See also,

⁵⁹ Staff *Post-Closure Maintenance Presentation* to CIWMB Permit and Enforcement Committee (November 3, 2003), Power Point Slide No. 18. CIWMB, Discussion Paper Regarding Postclosure Maintenance Beyond the Initial 30 Years and Financial Assurance Demonstrations (December 6, 2004).

⁶⁰ 40 C.F.R. §60.755(b).

most often from 100 Nm³/tonne, for the total methane potential, to double that, 200 Nm³/tonne.⁶¹ This means that, illustratively, in the case of a landfill that captures 75 Nm³/tonne, the choice of one or another end of the range can lead to a capture rate estimate of either 75% or 38%.

Ironically, the same Leatherwood memorandum that SCS earlier relied upon in an effort to support 75% as a minimum value for collection efficiency, demonstrates that this methodology cannot be used to estimate capture rates. For these estimates vary over such a wide range that virtually any conclusion can be reached depending upon which study is selected, according to Leatherwood, who also dismissed on the same grounds the work by Spokas and Bogner relied upon so heavily by SCS:

“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 variation within the 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 temporally. Thus, short-term measurements of uncontrolled LFG emissions only provide a snapshot of a changing emission dynamic. Since the calculation of LFG collection efficiency depends on uncontrolled emission levels, it too is a changing value. ...”

“Some studies of specific landfills and theoretical calculations of LFG production have resulted in models to predict uncontrolled LFG emission levels. However, these models have shown wide variation when applied to specific landfills, probably due to the site-specific factors that effect LFG generation and that measurements and models represent snapshots of a dynamic process. One recent reference (*Predicting LFG Generation and Extraction Using the EMCON Model*, 1997) states that a model will not actually replicate the site specific LFG generation, but should only bracket the potential range of LFG generation and that the extraction system efficiency must be determined by judgement...”

“As far as specific claims of collection efficiencies, Pacific Energy did claim to get 85 percent collection efficiency at their Toyon Landfill, 90 percent at their Penrose Landfill, and 95 percent at their Sheldon-Arleta Landfill. A comprehensive LFG fate study was recently conducted in France. 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

⁶¹ European Commission, *A Study of the Economic Valuation of Environmental Externalities from Landfill Disposal and Incineration of Waste: Final Appendix Report* (October 2000), at p. 144. There are other similar uncertainties with the companion value for the percent of gas generation in a single year, not to mention in the lack of any substantive precision in the often critical omitted factor, namely moisture 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. Based on discussions with an author of the paper documenting the French landfill studies, she noted that landfill methane generation models typically over-predict generation levels.”⁶²

Other studies that independently seek to verify work by Spokas and Bogner reach the same conclusion.

“Quantification of methane emission from landfills is important to evaluate measures for reduction of greenhouse gas emissions. Both the United Nations and the European Union have adopted protocols to ensure quantification of methane emission from individual landfills. The purpose of these protocols is to disclose emission data to regulators and the general public. Criteria such as timeliness, completeness, certainty, comparability, consistency and transparency are set for inclusion of emission data in a publicly accessible database. All methods given as guidance to landfill operators to estimate landfill methane emissions are based on models. In this paper the consequences of applying six different models for estimates of three landfills are explored. It is not the intention of this paper to criticise or validate models. The modeling results are compared with whole site methane emission measurements. *A huge difference in results is observed. This raises doubts about the accuracy of the models.* It also indicates that at least some of the criteria previously mentioned are not met for the tools currently available to estimate methane emissions from individual landfills. This will inevitably lead to compiling and comparing data with an incomparable origin. Harmonisation of models is recommended. This may not necessarily reduce uncertainty, but it will at least result in comparable, consistent and transparent data.”⁶³ (Emphasis added.)

Then, there are also further concerns with the very low assumptions of methane releases from landfills when using SCS and others high capture rate claims. Independent scientists have taken measurements of actual surface concentrations of methane around landfills, controlling for ambient levels, and found evidence that the industry assumptions may underestimate emissions by as much as 92%.⁶⁴

None of the studies relied upon by SCS to support very high assumptions of gas collection efficiency have any validity.

⁶² Leatherwood Memorandum, at pp. 1-2.

⁶³ Heijo Scharff, *Applying guidance for methane emission estimation for landfills*, 26 Waste Management 4 (July 2006). See, also, Joeri Jacobs et. al., *Comparison of Methane Emissions Models and Methane Emission Measurements*, at p. 14.

⁶⁴ David Lowry, et. al., *London methane emissions: Use of diurnal changes in concentration and $\delta^{13}\text{C}$ to identify urban sources and verify inventories*, 106 Journal of Geophysical Research 7427 (April 16, 2001).

Conclusion

The SCS report argues that the previously discredited EPA 75% capture rate assumption is actually too low instead of too high. Upon examination, there is no valid basis for this claim.

Although there is no field data to provide hard data in support of any particular value, at least the recent estimate by the Intergovernmental Panel on Climate Change uses the correct definition, that is, an estimate of what *average* gas collection systems over the *lifetime* that landfills generate gas:

“Some sites may have less efficient or only partial gas extraction systems, and there are fugitive emissions from landfilled waste prior to and after the implementation of active gas extraction; therefore estimates of ‘lifetime’ recovery efficiencies may be as low as 20%.”⁶⁵

Pending more solid data, this currently remains the best estimate for climate change planning purposes. The SCS report offers no valid basis for any higher estimation.

⁶⁵

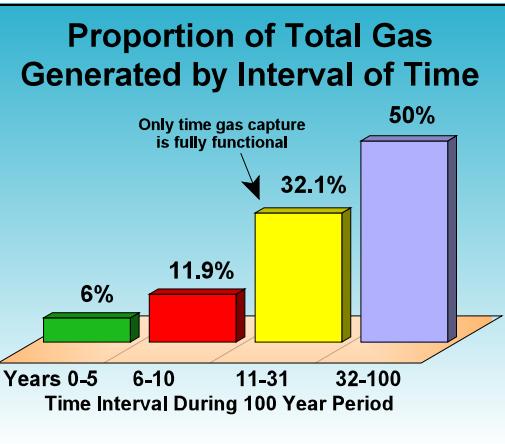
IPCC, *Fourth Assessment Report: Waste Chapter* (2007), at p. 600.

APPENDIX A

Lifetime, Not Point-in-Time, Efficiency Rate

EPA, and SCS, use a definition of collection efficiency that is patently wrong. EPA's 75% capture rate is actually conceptualized as an *instantaneous* rate.¹ That is one which is only applicable for the year in which the assumption is made. As applied, it is for landfills in which the collection systems largely are installed and mostly functioning, rather than to the entire *lifetime* that landfills generate gas.

That distinction is of overriding importance because EPA's Landfill Air Rule does not require gas collection for the first five years of a landfill's life.² Moreover, recent fundamental changes in operational practices at landfills, which contradict the dry tomb principles, have both significantly increased near term gas generation while also severely worsening gas collection efficiency. This *de facto* change, pursued to increase short term profitability, is a matter of utmost concern to society as the Earth's climate is at the precipice of a critical "tipping point."³



Furthermore, those rules allow removal of the collection systems from service approximately 16 years after the site's closure.⁴ Following the 30-year post-closure period when the landfill is no longer actively managed, the barriers "will ultimately fail," as the EPA has repeatedly acknowledged. Once the barriers fail, precipitation will re-enter the landfill, and, in time, accumulating moisture will cause a second wave of decomposition and gas generation without any controls.⁵

Therefore, substantial volumes of gas will be generated in both periods before and after the time when there is no or little gas collection – all of which is ignored by an instantaneous rate (see CHART).⁶ Because so much gas escapes without any or very limited controls, operators would have to capture 225% of the gas during the time gas collection is fully functional in order to achieve a lifetime rate of 75%. That is a mathematical impossibility, and, if the correct definitions are used, it shows the extreme difficulty in considering EPA's unsupported assumption to be within the realm of reasonableness.

EPA's continued use of an instantaneous rate, in the face of repeated efforts to bring this to the attention of the agency's staff, is also incompatible with the protocols set forth by the IPCC. The international agency overseeing the rules of the road for GHG accounting specifically states that the analysis "should be based on the effects of the greenhouse gases over a 100-year time horizon."⁷

Moreover, EPA's use of an instantaneous rate for the capture rate – which makes collection efficiency seem substantially larger than it really is – is also contradicted by the agency's inconsistent decision to turn around and later use a 100-year time period in other GHG calculations – where the effect is to reduce landfills' responsibility for GHGs.⁸

Correcting for the incorrect time frame definition – while leaving the EPA 75% value as an instantaneous rate – results in a corrected 100-year lifetime capture rate of only 27.1%. For there is no collection system for 56% of the gases landfills produce, and only a partially functional

one for another 12% of the time.⁹

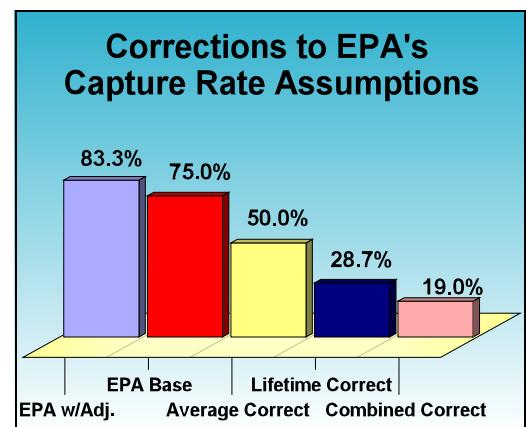
Average Instead of Best Operation

EPA also used the wrong definition of the appropriate landfill population upon which to base collection efficiency. It uses a *best-case* construct to illustrate what in the real world is represented by the *average* landfill.

The Agency acknowledges that it defines its assumed collection efficiency rate to be for “well-managed sites,” and what sites “should or could achieve,”¹⁰ rather than what the weighted average of all landfills actually attains. This even though it previously acknowledged the self-evident fact 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.”¹¹

Because there is presently no way to measure landfill gas emissions,¹² nor any emission rate or air quality standard to enforce even if there were,¹³ in the private sector there would be no incentive to minimize gas emissions. The only constraint would be the palpable need to prevent subsurface migration into adjoining structures that cause explosions and to reduce offensive odors to nearby neighbors on hot days that cannot be achieved with misting or buyouts.

Nor, as elaborated upon later, does EPA impose any specific design requirements for control systems other than it be an undefined and unenforceable “well-designed and well-operated gas collection system.” Similarly, as also discussed below, neither have regulators prevented the new practices in the landfill industry that further reduces the effectiveness of the design and operation of typical collection systems over time.



Thus, there is little basis to contend that actual performance in the field resembles the best of what can theoretically be achieved.

No one knows what the average capture rate is for systems that are up and running. But, the weight of independent guesstimates in the technical literature are in the range of 40% to 50%, centering on 40%.¹⁴ If one generously uses an assumption of 50% for the average instantaneous rate to reflect typical conditions, that would reduce the 27.1% efficiency factor (which reflected the correction of the instantaneous 75% rate to a lifetime rate) to 19% (see CHART above).¹⁵

ENDNOTES

¹ [EPA assumption for landfill gas collection efficiency is intended to be an instantaneous rate]

EPA's published documents fail to elucidate how they went about formulating their assumptions. We interviewed three agency officials central to the process to determine whether the assumed 75% capture rate was intended to be based upon an instantaneous or lifetime period, and all of those interviewed stated that it was to be an instantaneous rate. Interviews by Peter Anderson with Henry Ferland, Dina Kruger and Elizabeth Scheele at U.S.E.P.A (Sept. 8, 2003).

² [EPA landfill air rule permitting delay in installation of gas collection equipment for 5 years]

40 C.F.R. §60.755(b). In reality, the food segment of biodegradables is largely decomposed in less than a year, while paper, especially coated forms, can take years to decay. Hans Williamsen, "Production & Use of Landfill Gas," *Paper for International Conference on Solid Waste Management and Technology* (Lisbon, October 1997), at pp. 3-4. William E. Eleazer, et al., "Biodegradability of Municipal Solid Waste Components in Laboratory-Scale Landfills 31 *Environmental Science & Technology* 911 (1997). ECON, *Miljøkostnader ved avfallsbehandling* (Oslo, December 2000), at p. 74, TABLE 4.11. EPA's only stated justification for delaying by three years when substantial gas generation occurs the time to install gas collection equipment was to reduce costs for the new mega-sized landfills as part of the agency's "common sense" initiative. 61 FED. REG. 49 at p. 9911 (March 12, 1996).

³ [Critical impact on near-term landfill gas generation due to change from dry tomb to wet cell operation]

In the last 5 to 10 years, the manner in which landfills are operated has changed in a most fundamental way from the original intent of Subtitle D, and that change carries very substantial implications for climate change.

Increasingly, a new operational philosophy has supplanted statutory and regulatory efforts to keep the landfill dry "like a tomb" with barriers in order to temporarily stabilize garbage. 40 C.F.R. §258.28. Now efforts are being made to deliberately add moisture in order to accelerate decomposition. These include recirculating leachate, delaying installation of the cover so more rainfall can enter the waste body, grading to capture surface runoff, and, taken to its conclusion, adding sewage sludge in bioreactor landfills to accelerate decomposition. Debra Reinhard, "The bioreactor landfill; Its status and future," 20 WASTE MGMT. & RES. 2, pp. 172-186 (2002).

However, in those first years of the life of a landfill undergoing accelerated decomposition, the volume of landfill gas that is generated in the near-term is thought to be 2 to 10 times greater than was contemplated under the original terms of the agency's landfill rules, 67 FED. REG.100, at pp. 36463 and 36465 (May 22, 2002),

That one magnitude shift in gas generation from the distant future to the near term is at a time that two major concerns affecting air emissions are created. First, this is before gas collection systems have been installed, 40 C.F.R. §60.755(b), which is when no gas collection occurs. Second, this also extends beyond the initial five years for several more years after the gas collection pipes are present, but during which installation of a final cover is delayed in order to let in more liquids. Indeed, in practice these covers may often be delayed indefinitely because of the intractable practical problems the industry has experienced stabilizing caps layered over the same slippery geomembranes employed in an effort to retard infiltration. The prolonged absence of the cover represents a critical impairment for gas collection because, without that barrier on top, the collection systems function poorly, if at all, as they draw air into the pipes from the open surface along with the gas from the surrounding waste field. When this occurs and more than 5% methane mixes with oxygen, explosive conditions are created, short circuiting the system and requiring the well to be shut or damped down. 40 C.F.R. §60.753(c).

Not only is gas collection efficiency absent or degraded during this time that accelerating decomposition causes gas production to rise dramatically, but also, the same 40%-70% levels of moisture needed to accelerate decomposition, George Tchobanoglous, *Integrated Solid Waste Management* (McGraw Hill, 1993), at pp. 72-73 and 393; G. J. Farquhar, "Gas Production During Refuse Decomposition." 2 *Water, Air and Soil Pollution* 9, at pp. 483-495 (1973), exacerbates effective gas collection further. Because rapid differential settlement would tilt and snap the vertical rigid plastic wells normally used to collect gas, flexible pipes laid down horizontally are resorted to instead. These drainage pipes can and do collapse under the weight of the compactors used to densify the landfills' wastes. Also, in order to reduce expenses, the same pipes are often used to remove gas as are used to inject liquid. As a result, gas generation can occur when there is no collection, and, when the pipes' use is switched back to collection, they can become saturated, making effective gas collection impossible.

To make a deliberate decision to ramp up near term gas generation, at the same time gas generation is ineffective, presents additional climate change concerns. Recent analysis has concluded that the planet is at a climatic tipping

point during which all efforts need to be made to decrease, not increase, GHG emissions. James Hansen, “Dangerous human-made interference with climate,” 7 ATMOS. CHEM. PHYS. 2287-2312 (2007).

For the private waste industry companies, increasing moisture levels is projected to recover approximately a quarter of the volume in a landfill due to the resulting subsidence so that the same airspace can be resold a second time at little cost to the company. Christopher Campman and Alfred Yates, “Bioreactor Landfills: An Idea Whose Time Has Come,” *MSW Management* (Sept/Oct. 2002), at TABLE 1. Also, the need to make the substantial monetary and political expenditures to qualify a new site can be delayed. And, of course, recirculating leachate reduces their costs to treat the effluent. This creates powerful economic incentives for the industry to pursue the practice. However, that rational economic behavior at the level of the firm is in conflict with very significant social costs that regulation is intended to rectify. Unfortunately, the opposite is the case here, namely is abetting anti-social practice rather than restraining it.

Recent rule changes by EPA indicates that the current practice by the landfill industry to encourage liquid additions, which is contrary to the express prohibitions in the existing rules that ban the practice, 40 C.F.R. §258.28, can be effectively continued and expanded upon without substantive regulatory intervention.

In 2004 EPA promulgated a new rule that essentially authorizes landfills in states that are approved to enforce RCRA inside their jurisdiction to aggressively add moisture and delay installing a final cover so that the landfill owner can recover air space and reduce leachate treatment costs. Furthermore, in view of the fact that there is no discussion of the subject of the consequences in the Federal Register, EPA apparently did this without any consideration of the profound impacts of these changes on near-term methane emissions. 69 FED. REG. 55, at pp. 13242-13256 (March 22, 2004).

The rule states it is intended to encourage research to provide data for the new design principle erected on saturated conditions(as well as to encourage research on alternative covers), which is diametrically different from the dry tomb design principles in the current code.

However, the wording of the rule provides for something that is difficult to reconcile with *bona fide* research. Specifically, nothing in the RD&D rule imposes any limit on the number of research efforts, thus permitting almost all landfills to operate in violation of the current code ostensibly in order, presumably, to test and retest *ad infinitum* the exact same issue. In addition, the rule does not even require that there be a study design or standardized protocols for comparability and reliability, nonetheless a test that EPA has indicated meets a valid research need to develop wet cell rules. Moreover, it does not even provide that the results of any research are to be submitted to EPA so that the findings can actually be used in rule development.

Because the RD&D rule also contains no specific and enforceable standards for wet cells, it bears more resemblance to federal authorization for states to permit a new generation of wet cell landfills without the federal minimum standards that the Resource Conservation Act Amendments of 1984 require. 42 U.S.C. §§6901-6992.

While the rule does purport to require that the hydraulic head on the bottom liner be kept less than 30 cm, 40 C.F.R. §258.4(2)(b), that putative requirement is made effectively meaningless by the fact that there is no reliable instrumentation to measure the depth of leachate pooling at the bottom of a landfill hundreds of feet below and heavily compacted to more than a ton per cubic yard. Debra Reinhart, “Bioreactor Challenges,” *US EPA Workshop on Bioreactor Landfills* (February 27, 2003). Also, although there are separate bioreactor landfill standards requiring that an active gas collection system be installed within 180 days instead of the five years for dry tomb landfills, 40 C.F.R. §63.1947(a), that requirement is met in most cases by claiming the same flexible (and collapsible) horizontal tubes used to inject liquids can alternately be used to remove gases. Flexible horizontal pipes, in saturated conditions and under enormous weight that often crushes the tubes, are unlikely in most real-world cases to have even a fraction of the efficiency of rigid vertical wells under dry conditions. Moreover, there is no necessary requirement to lay a low permeable cover on top to perform the essential task of preventing oxygen infiltration so that the systems will not continually short circuit.

In the last analysis, the only enforcement provision in the RD&D rule is a undefined, and unenforceable, requirement that its permits should “include such terms and conditions at least as protective as the criteria for municipal solid waste landfills to assure protection of human health and the environment.”

If an analysis of landfills’ GHG emissions is to have any relationship to the facts on the ground, the basis for those estimates should recognize with as much field data as can be garnered how these changes will affect near term gas emissions.

to fall below 55 tons per year, gas collection can be removed from service (so long as the landfill is closed, the gas system has operated for 15 years and the 55 tpy limit is rechecked on three subsequent dates between 90 and 180 days apart).40 C.F.R. §60.752(b)(2)(v)(C).

Just before the air rule was promulgated in 1996, EPA estimated that, using this site specific process, approximately 39% of regulated landfills will be able to remove the systems from service by the 10th year following closure of the landfill. The average was the 27th year. US EPA, *Air Emissions from Municipal Solid Waste Landfills* (1995), at pp. 3-12, Table 3-4. However, this seems likely to significantly underestimate the actual time that their 1995 analysis suggested.

Subsequent to the time EPA did this analysis, it revised the assumptions for the inputs used to calculate non-methane emissions that drive the end-point. That had the effect of reducing those pencil estimates of how long the landfills would be required to operate gas collection after closure by about 40%. 56 FEDERAL REGISTER 24494 (May 30, 1991).

At the same, the final rule made the emission rate cutoff lower, from 150 to 50 metric tons per year of non-methane organic compounds, 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 for its first order decay model in 40 C.F.R. §60.754(a).

Unfortunately, EPA's analysis does not break out data from within the reported ranges to recompute the proportion of landfills that will be required to keep their gas systems operational for the different lengths of time that the new inputs imply. For purposes of discussion, 16 years is used, which is the same 40% less than the 27 year average, recognizing that the actual number may be somewhat different in either direction and subject to refinement as more experience becomes available.

5

[Second wave of landfill gas and leachate generation after closure]

For the effect that the barriers will eventually fail, see, e.g., 53 FEDERAL REGISTER. 168, at pp. 33344-33345 (August 30, 1988). 46 FED. REG. 11128-11129 (February 5, 1981). Similar: "A liner is a barrier technology that prevents or greatly restricts migration of liquids into the ground. No liner, however, can keep all liquids out of the ground for all time. Eventually liners will either degrade, tear, or crack and will allow liquids to migrate out of the unit. Some have argued that liners are devices that provide a perpetual seal against any migration from a waste management unit. EPA has concluded that the more reasonable assumption, based on what is known about the pressures placed on liners over time, is that any liner will begin to leak eventually." FEDERAL REGISTER (July 26, 1982), at pp. 32284-32285.

For the effect that the failure of the barriers will lead to a second wave of gas generation, see, e.g. CIWMB, Discussion Paper Regarding Postclosure Maintenance Beyond the Initial 30 Years and Financial Assurance Demonstrations (December 6, 2004) (emphasis added). On-line at: <http://www.ciwmb.ca.gov/Agendas/agenda.asp?RecID=1015&Year=2004&Comm=PEN&Month=12>. Staff Post-Closure Maintenance Presentation to CIWMB Permit and Enforcement Committee (November 3, 2003), Power Point Slide No. 18.

6

[Calculation of the proportion of gas generation in each time period of a landfill's life]

There are five phases of a landfill's life during which gas is generated subject to markedly different collection efficiencies: namely (i) before installation of the gas collection system (years 0 to 5); (ii) before installation of a final cover (6 to ~10); (iii) during landfill operation (11 to 30); (iv) during the postclosure period (31 to 60); and (v) after postclosure ends (61 to 100).

Model selection. EPA calculates gas generation over any specified time period using the First Order Decay (FOD) model—

$$Q_m = L_o \times R \times (e^{-kc} - e^{-kt})$$

where:

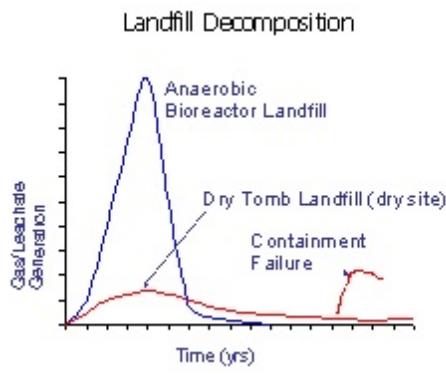
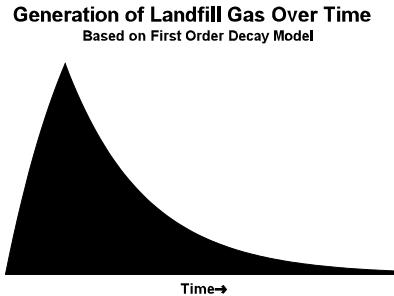
Q_m	=	Methane generated in current year (m^3)
L_o	=	Methane generation potential (m^3/Mg of waste)
R	=	Average annual waste acceptance rate (Mg/yr)
k	=	Methane generation rate constant
c	=	Years since landfill closure
t	=	Years since landfill opening

Turning a Liability into an Asset: A Landfill Gas-to-Energy Project Development Handbook (EPA 430-B-96-004 (September 1996), at p. 2-5; 40 C.F.R. §60.754(a)(1).

FOD equations do describe the manner in which the resulting emissions from a finite mass would occur during continuous release, as an increasing segment of the mass becomes decomposed and is not subject to decomposition in the following years. But, it does not work when decomposition is incomplete due to inadequate moisture, soon to be essentially interrupted as moisture levels fall too low for any noticeable decomposition, and thence resumed at a later time, which is what is anticipated at lined landfills when the barriers “ultimately fail.” For that reason, we made the following adjustments to the FOD to reflect those releases that are delayed in order to model the proportion of gases generated in those five time periods.

Second wave adjustment to FOD model. The plot traced by the standard FOD model is shown in the accompanying figure to the right. This model does track the quick rise as landfill volume is increasing, and a sharp fall off in generation of gas after the site is closed, which is associated with decomposition of a specified volume of municipal solid waste of a certain composition *when in the continuous presence of adequate moisture* that is a limiting condition to sustain decomposition. US EPA Office of Air Quality Planning and Standards and Office of Air and Radiation, *Emission Factor Documentation for AP-42, Section 2.4, Municipal Solid Waste Landfills* (Revised August 1997); US EPA, *Anthropogenic Methane Emissions in the United States: Estimates for 1990* (Report to Congress) (EPA 430-R-93-003)(1993), at p. 4-8. Inasmuch as this condition soon ends, a major adjustment to the FOD model is needed to track how this interruption impacts when the latent gas potential remaining in the entombed wastes ultimately is released. For that reason, the correct curve to use would not resemble a Dromedary (single-backed), but rather a Bactrian (or double-backed) camel, in which there is a second wave of gas generation after postclosure care

constructively ends. The California Integrated Waste Management Board (CIWMB) has stated a bi-model distribution is needed to reflect this fact as shown in the graphic to the left. Staff, *Post-Closure Maintenance Presentation* to CIWMB Permit and Enforcement Committee (November 3, 2003), Power Point Slide No. 18.



Landfills operated under the original terms of Subtitle D and are new sources subject to the landfill air rule, 40 C.F.R. Part 60 WWW, quickly become dehydrated. The approximate 20% gross moisture content entrained in the waste disposed of in a landfill, which is necessary for decomposition to progress, George Tchobanoglous, *Integrated Solid Waste Management* (McGraw Hill, 1993), at pp. 72-73, will very soon be removed by gas collection systems as half of the gas that is excavated escapes from the landfill consists of moisture in a properly operated and maintained dry tomb facility.

Assuming 100% saturation, at 40° C (104°F), the condensate is 51% of the weight of the gas, according to standard Humidity Tables, and landfill gas weighs 0.0834 lbs./cf. This suggests that condition-limiting moisture levels would decline from 20% to 12.5% after 10 years, to 10% after 20 years, and 7.5% after 30 years, thereby sharply constricting the amount of gas generated after not later than 10 years to far less than is full potential (which is the L_o factor in the FOD equation).

Moreover, on a localized basis, only some of the recirculated moisture actually reaches many parts of a landfill due

to the fact that MSW is highly heterogeneous and exhibits pronounced preferred-paths-of-flow through channels and openings where larger or more rigid particles bridge in a waste mass that, except for those pore spaces, is heavily compacted to as much as 2,200 pounds per cubic yard. Also, much of the garbage is contained in plastic bags, which, even if splayed open on the sides from compaction, still creates a horizontal barrier that impedes vertical flow. In addition, many types of daily covers exhibit low permeability retarding vertical in further favor of horizontal distribution of liquids. Finally, liquid recirculation is usually restricted near the sidewalls in order to reduce the occurrence of seepage and breakouts. This strongly suggests that not insignificant proportion of the carbon value in the organic fraction of solid waste is not decomposed by the time the site has become dehydrated and extending through past closure until the time the final cover fails and a second wave of gas generation is reignited.

The amount of undecomposed waste to adjust for in closed landfill. A comparison of subsidence in dry tomb to bioreactor landfills suggests that less than half of the eventual decomposition will have occurred in a dry tomb landfill prior to closure, M. El-Fadel et al., "Modeling Settlement in MSW Landfills: A Critical Review," *Critical Reviews in Environmental Science and Technology* (2000), at p. 327; and Christopher Campman and Alfred Yates, "Bioreactor Landfills: An Idea Whose Time Has Come," *MSW Management* (Sept/Oct. 2002), at TABLE 1, albeit only if subsidence is an appropriate proxy for decomposition..

As a cross-check, the approximate magnitude of the remaining carbon can be illustrated mathematically by examining the limited observations that have been made of gas generation over time. EPA has noted that gross observations show that most landfill gas appears to be "generated within the first 30 years [from first waste emplacement]." US EPA, Changes to the Methodology for the Inventory of Methane Emissions from Landfills, dated August 26, 2004, at p. 3. Similarly, more recent evaluation of this issue by the waste industry has also found that leachate volumes taper off by the 9th or 10th year after closure. The EPA's observation that methane generation ends about 30 years from first waste emplacement converts to the same as the industry's 10th year after closure number. This is because, from the point of first waste emplacement, there will usually be about 20 years of landfill operation before closure.

US EPA's recent attempts in the late 1990s to characterize this observation as proof that the site has stabilized is not only contrary to their candid admissions through the 1980s in the Federal Register cited earlier, but also is based upon incorrect principles. For these observations are a mixture of long closed unlined landfills, which are irrelevant here because they do not retard gas generation with covers; or of Subtitle D landfills, but, because they only have been in use for about 15 years, for too limited a time to experience second wave releases.

Here, where the question is the proportion of the original carbon content remaining with the waste after closure, something else becomes evident that makes EPA's characterization untenable when the FOD model is run.

The model designates the lifetime total methane generation potential as " L_o " per unit of waste, which is calculated from previously reported laboratory experiments and observations. US EPA, *Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks* (EPA530-R-02-006) (June 2002), at p.98.

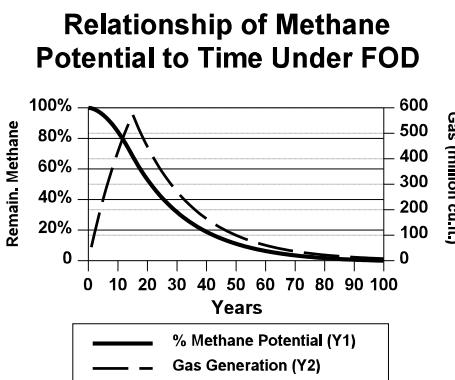
Then, the amount of methane generation in a given year is estimated by multiplying L_o by an exponential function of k , as is shown if the formula at the top of this note. The variable k is the fraction of the remaining organic discards that decomposes each year. It can be adjusted, but not by too much or it will be at variance with observations in the early years about which, unlike the long term, so much of the data exists.

We ran the FOD model using US EPA's standard input values of $L_o = 2.72$ c.f./lb. and $k = 0.05$, as specified in, among other EPA sources, *Turning a Liability Into an Asset* (EPA 430-B-96-0004)(September 1996), at p. 2-6, and in the Federal Register, 57 FED. REG. 33791(June 21, 1993), and in EPA's landfill air rule, 40 C.F.R 60.754(a)(1).

When the FOD model is run using the Agency's own value for L_o , a fatal problem arises for EPA's claim that the landfill is stabilized when closed. This is because the model shows gas generation continuing long after 10 years after closure when EPA said it observed emissions to end.

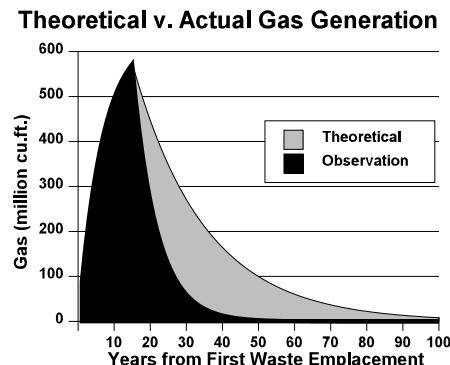
The graph along side to the right represents the first order decay model, adjusted to show the residual gas generation potential each year that remains after the decomposition that has occurred up until that year. (Along side for reference is the same FOD plot of estimated gas quantities by year as was shown before.).

Note that, in contrast to US EPA's previously observed tapering off of gas production 10 years after closure, the decay trail calculated from the FOD model does not end until around 63 years (when



defined to be less than 5% of peak generation).

The key point is that emissions from Subtitle D landfills are observed to end much sooner than would be expected by the decay function using the original estimates for L_o . That difference between observation and calculation is consistent with a situation in which gas production in a lined landfill during the first wave is significantly incomplete due to inadequate moisture levels discussed earlier in the text. Major volumes of convertible carbon remain with the waste for a second wave because the waste cannot be isolated in perpetuity.



The next chart to the left shows what this exercise has demonstrated. The dark area to the left under the first plot represents the gas generation that EPA has been observed, which trails off rapidly following closure. The next plot to the right is the trend indicated the FOD model, which is what would have been observed were the first order decay model a correct reflection of the real world. However, not only do they not coincide: they are substantially different.

The major difference between the theoretic and observed emissions of landfill gas is the area shown with diagonal lines, which approximates the observed short term emissions. That area represents the large proportion of convertible carbon that has not yet been degraded during the first wave of decomposition because of insufficient moisture. This is what is carried over into the future after the cap, when it is no longer maintained, deteriorates, letting in a second wave of infiltration, decomposition and gas and leachate generation.

Presumably, in light of these inferences, US EPA is expected to challenge the use of its own value for L_o . In the succeeding years that followed the repeated use of L_o as 2.72 c.f./lb., the agency began to sharply reduce the value of L_o to nearly half their original statement for this parameter, such as in its emission factor document, referred to as AP-42, US EPA, *Compilation of Air Pollutant Emission Factors* (AP-42)(5th Edition 1998), at p. 2-4, contending that those earlier values were too conservative. Were that subsequent readjustment the correct one to make, the mathematical quandary with the agency's position that is explained above would be avoided.

However, there are four serious problems with US EPA's new assertion that the original value for L_o is too conservative and was never meant to reflect average conditions. First, EPA's own Inspector General found that, in general, EPA tended to lower emission factors because, otherwise, industry would be "potentially subject to stricter regulations and State or local air toxics rules." Inspector General, *EPA Can Improve Emissions Factors Development and Management* (Report No. 2006-P-00017)(March 22, 2006), at p. 15.

Second, the original report, *Turning a Liability Into an Asset*, was written to "provide[] the landfill owner/operator with basic screening criteria to assess the viability of a landfill energy recovery project." *Id.*, at p. 1-1. To suggest that the more recent values is meant to add conservatism to the earlier estimate would have been inconsistent with the purpose of a users' worksheet, which in this context, would have doubled the volume of gases to expect to collect and convert to energy. That would have encouraged perhaps twice as many landfill owners as was justified to make significant investments in energy projects that were not economically justified. That is difficult to credibly describe *post hoc* as a conservative choice.

Third, EPA's AP-42 downward revisions were based upon reported measurements of gas volumes captured in gas collection systems as a function of waste-in-place. However, for one thing, when we delved into the details of this data, EPA staff conceded that reporting to the agency is often based upon the nameplate capacity of the systems, not actual gas flows. Moreover, since any valid information about the volume of gas that was collected says nothing about the total gas generated, those questionable "observations" were converted into totals by use of the same arbitrarily assumed 75% instantaneous capture rate, per the formula:

$$\text{Total Gas Generation} \times \text{Capture Rate} = \text{Observed Gas Generation}$$

$$\text{or Total Gas Generation} = \text{Observed Gas Generation} \div \text{Assumed Capture Rate}$$

That is to say, AP-42's change in the value for L_o is based upon circular logic that is only valid if its 75% assumption is correct. As detailed earlier in NOTE 21, that high a value of 75% would only be appropriate for optimally installed and operated systems, while average systems, which are the appropriate benchmark, are unlikely to exceed 50%, and more likely 40%. If the corrected capture rate is used, then the value for L_o using this methodology would conform with EPA's original estimates.

Third, our calculated plot with EPA's original input values reassuringly parallels observations of landfill gas generation in pre-Subtitle D landfills without liners in which gas production was observed to continue for approximately 50 years. G. Fred Lee and Anne Jones-Lee, *Municipal Landfill Post-Closure Care Funding: The '30-Year Post Closure Care' Myth* (Monograph 1992), at p. 4. For not until Subtitle D took effect did barriers come into common use created a temporary interruption in moisture levels inside enclosed landfills.

We have long urged that statistically drawn bore samples be taken from landfill cells at different times to quantify how much carbon remains after closure. Unfortunately, the waste industry has indicated a greater preference in advancing convenient, unsubstantiated theories in the pursuit of shorter, and less expensive, postclosure periods than the collection of statistically valid data. Our efforts to convince regulators to require this data as part of the earlier Project XL programs have been rejected. 67 FED. REG. 138, at pp. 47310-47320 (July 18, 2002) (involving Waste Management's King George and Maplewood Landfills in Virginia).

In the absence of hard data, the working assumption in this paper, based upon the foregoing analysis, is that half of the original carbon remains when the gas collection systems are shut down.

7

[IPCC rules require lifetime emissions over time]

Intergovernmental Panel on Climate Change, *Second Assessment - Climate Change 1995* (1995).

8

[EPA inconsistently uses 100-year time period to convert methane into carbon dioxide equivalence]

In calculating greenhouse gas emissions, the different types of warming gases are converted into a carbon dioxide-equivalent basis for ease of comparison. To do this, the fact that methane breaks down in the atmosphere over a shorter interval than CO₂ must be accounted for. EPA uses a 100 year time to recognize CO₂'s longer residence time than CH₄. If instead, EPA consistently used a single year as the time period for calculation, the multiplier to convert CH₄ to a CO₂-equivalent basis would be more than *twenty times* the 23× conversion factor that EPA currently uses in estimating landfills' GHG responsibility. EPA's use of diametrically opposite time periods for comparison, applied improbably in a way that consistently minimizes landfills' responsibility for GHGs, is not easily explained on a rational basis.

9

[Estimate of collection efficiency when only correcting instantaneous to lifetime rate]

The mathematics for this calculation is as follows:

Period When Collection is at-	Proportion of Gas Generation	Collection Efficiency During Period	Weighted Collection Efficiency
Full Efficiency	32.1%	75.0%	24.1%
No Efficiency	56.0%	0.0%	0.0%
Partial Efficiency	11.9%	25.0%	3.0%
Total			27.1%

10

[EPA's capture rate assumption is based upon estimate of best not average system]

US EPA, *Anthropogenic Methane Emissions in the United States* (EPA 430-R-93-003), at p. 4-11 (emphasis added). This policy continues to pervade the discussions that EPA holds on landfills' estimated GHG emissions, which consistently have those who advocate high values for collection efficiency preface their comments with words to the effect, "in a well managed site." In the Leatherwood memorandum relied upon by EPA, he references the typical sort of characterization of how the question is defined: "[a] few other contacts and references stated that newer landfills that are lined and capped with a geomembrane cover *should achieve* greater than 90 percent collection efficiency." Memorandum to Brian Guzzone, EPA, 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.

11

[EPA concedes average emissions are benchmark for estimating GHG emissions]

EPA, *Anthropogenic Methane Emissions in the United States* (EPA 430-R-93-003), at p. 4-12 (emphasis added).

¹²

[No means to measure landfill gas emissions.]

See NOTE 6.

¹³

[No enforceable emissions standard for releases from landfills]

The foundation of the US EPA landfill air rule is that there be “a well-designed and well-operated gas collection system,”⁴⁰ C.F.R. §60.752(b)(2), but that vague admonition is general and subjective, and has no specific requirements that could be enforced.

The only provision in the landfill air rule that might appear to create a standard is one that is intended to limit concentrations of methane at the surface to 500 ppm, or the so-called “sniff test.” 40 C.F.R. §60.753(d) and §60.755(c). But, first, our research shows that the sniff test was developed by the South Coast Air Quality Management District in the early 1980s because methane was believed to be a precursor of odor complaints by neighbors, and at levels greater than 500 ppm, odor complaints were noted in that semi-arid region. But, there is no relationship whatever between 500 ppm and what needs to be done to truly minimize GHG emissions from landfills to meet the demands of a coherent global warming strategy, that did not exist as a construct at that time.

Second, this test is predicated upon a regimen that only works if emissions are diffused across the entire face of the landfill, which is usually no longer the case at Subtitle D landfills. Most of them are designed to have low permeable geomembranes that limit most releases to a few localized tears in the liners. Using a Poisson Distribution, the statistical probability of detecting 10 leaks at a landfill is 2.3974227905e-38, and that is even if the test could not be gamed by careful timing, which it can and is because emissions are so closely correlated with barometric pressure and moisture.

The only actual test for landfill air emissions uses a protocol that statistically is unable to detect significant leaks, and, in any event, has no relation to minimizing methane emissions as opposed to offensive odors to neighbors.

¹⁴

[Estimates in the technical literature outside waste industry of gas collection efficiency rates while operating center on 40%]

The literature from non-waste industry sources tends to assume in the order of 40% capture rates, with a range of 34% to 50%. See, e.g., Forbes McDougall, Peter White, *et al.*, *Integrated Solid Waste Management: A Lifecycle Inventory* (Aspen Pub. 1999), at p. 275 [40%]. See, also, 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 Wietersaari, “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%]; and Hans Williamson, “Production and Use of Landfill Gas: Energy Recovery,” Paper for International Conference on Solid Waste Management & Technology (Lisbon, October 1997) [25% - 50%].

Casting further doubt on “bottom-up” high capture rate assumptions is a completely different “top-down” approach that directly measures methane concentration in the atmosphere around landfills after controlling for air movement. Ambient levels substantially higher than bottom-up assumptions were routinely found. Fred Pearce, “Kyoto promises are nothing but hot air,” *NewScientist* (June 22, 2006).

¹⁵

[Calculation of landfill gas collection efficiency corrected for average experience]

The mathematics for these calculations are as follows.

Period When Collection is at-	Proportion of Gas Generation	Collection Efficiency During Period	Weighted Collection Efficiency
Full Efficiency	32.1%	50.0%	16.1%
No Efficiency	56.0%	0.0%	0.0%
Partial Efficiency	11.9%	25.0%	3.0%
Total			19.0%