THE IMPORTANCE OF LANDFILL GAS CAPTURE AND UTILIZATION IN THE U.S.

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EXECUTIVE SUMMARY

According to the BioCycle/Columbia survey of municipal solid wastes (MSW), the U.S. generates nearly 400 million tons of MSW, 64% of which is landfilled. When MSW is buried in a landfill, a complex series of reactions occur in which anaerobic microorganisms decompose a portion of the organic fraction of the waste to carbon dioxide and methane. The methane produced can be collected and flared or converted to energy, which oxidizes the methane to carbon dioxide.

In its Fourth Assessment Report, the Intergovernmental Panel on Climate Change (IPCC) estimated that mitigation of methane from the world's landfills, by means of gas collection and utilization could reduce methane emissions from landfills globally by 70 percent at negative to low costs by 2030. In effect, IPCC recommended a waste management method that is widely employed in the United States.

Unfortunately, opponents to landfill disposal too often do not differentiate between those practices that are helpful and those that are detrimental from a Climate Change perspective. When landfills are reviewed on a life-cycle basis, the negative comments from landfill opponents do not accurately portray the greenhouse gas (GHG) emissions from landfills in the United States, and data are often misused to suggest that landfills are collecting far less of the landfill gas (LFG) than actually is occurring nationwide. Recently, these opponents have urged policymakers not to support measures aiming to increase LFG capture and recovery. The main argument is that increased LFG capture makes composting less attractive than landfilling.

The United States has a very stringent level of regulation with regard to LFG and has the highest percentage of landfills with LFG collection systems relative to any other country that practices landfilling. Because of regulatory as well as other programs that promote LFG recovery and utilization, such as the Landfill Methane Outreach Program (LMOP) of the U.S. Environmental Protection Agency (USEPA), nearly 60% of the worldwide capture of methane occurs in the United States even though the U.S. only generates 24% of the worldwide methane.

Despite the progress made in capturing LFG, methane emissions from landfills can be further reduced by regulations and incentives that will result in additional LFG capture and utilization by means of:

- Improving the design and construction of the LFG collection system to improve efficiencies,
- Increasing LFG collection system efficiencies by improved cap and cover systems.
- Promotion of earlier installation of gas collection systems.

It is these types of improved control measures that should be the focus of efforts to further reduce methane emissions from landfills, including any incentives, financial or otherwise, that encourage more and earlier LFG collection as well as the beneficial use of the collected LFG to create additional GHG reductions by generating renewable energy.

Organics diversion, composting, and/or other waste management options, which are sometimes viewed as alternatives to landfills, are more properly considered as complementary waste management tools. All such practices must be judged on their own merits, including cost-effectiveness, environmental impacts and operational efficiency, and not on the back of unfounded negative statements about landfills or other management options. Progress in lowering GHG emissions is best achieved by a concerted, integrated approach that employs all available technologies and methods, including reuse, recycling, composting, waste-to-energy, and landfilling with capture of LFG.

Table of Contents

Section

List of Figures

No. **Page**

List of Tables

No. **Page**

THE IMPORTANCE OF LANDFILL GAS CAPTURE AND UTILIZATION IN THE U.S.

1.0 INTRODUCTION

1.1 BACKGROUND

Progress in lowering GHG emissions is best achieved by a concerted, integrated approach that employs all available technologies and methods, including reuse, recycling, composting, waste-to-energy, and landfilling of municipal solid wastes (MSW) with capture of landfill gas (LFG). This "hierarchy" of waste management is illustrated in Figure 1.1 (Kaufman and Themelis, 2009).

Figure 1.1. The Hierarchy of Waste Management (Kaufman and Themelis, 2009)

In the United States, the biogenic components (paper fiber, food wastes, wood, etc.) of MSW are composed of approximately 30 to 50 percent cellulose, 7 to 12 percent hemicellulose, and 15 to 28 percent lignin on a dry weight basis, with cellulose and hemicellulose representing about 90 percent of the biodegradable portion of the MSW (Hilger and Barlaz, 2001). When MSW is buried in a landfill, a complex series of reactions occur in which anaerobic microorganisms decompose a portion of the organic fraction of the waste to carbon dioxide and methane.

The methane produced may be collected and flared or converted to energy, which oxidizes the methane to carbon dioxide. The methane can also be oxidized to carbon dioxide by methanotrophic bacteria in the landfill cover soil. Therefore, the ultimate fate of carbon placed in the landfill is sequestered or emitted as methane or carbon dioxide (Barlaz, 2007). In terms of atmospheric input, methane from landfills is considered an anthropogenic source of carbon while the carbon dioxide is considered biogenic in origin and not an anthropogenic source. Figure 1.2 depicts a simplified representation of the methane mass balance in landfills.

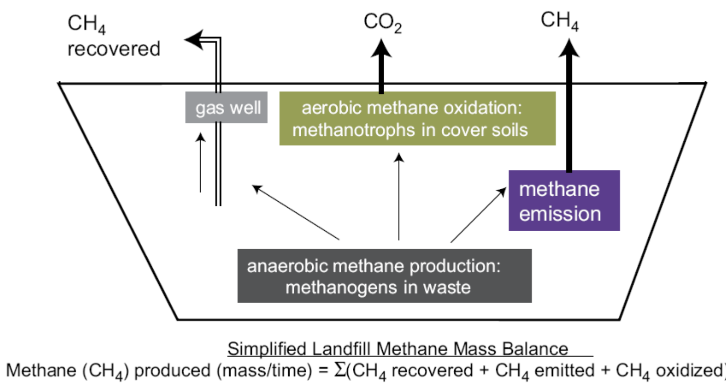

Figure 1.2. Simplified Landfill Methane Mass Balance (from Bogner et al, 2007)

1.2 SUMMARY

The methods used for management of waste affects the release of greenhouse gas (GHG) emissions in several ways, including the amount of methane emissions from landfills. The U.S. Environmental Protection Agency (USEPA, 2009a) estimates that landfill methane accounts for about 4% of all U.S. GHG emissions, measured in terms of global warming potential (GWP). According to the Intergovernmental Panel on Climate Change (IPCC, 2006), the waste sector, including solid waste and wastewater, account for less than 5% of global GHG emissions. In its Fourth Assessment Report, IPCC estimated that mitigation of methane from landfills throughout the world through collection and control could reduce methane emissions from landfills globally by 70 percent at negative to low costs by 2030 (IPCC, 2001). In effect, the IPCC points to waste management methods widely employed by the United States as evidence of the practices that, if used worldwide, could significantly fight Climate Change on a global basis.

Unfortunately, opponents to landfill disposal too often do not differentiate between those practices that are helpful and those that are detrimental from a Climate Change perspective. When landfills are reviewed on a life-cycle basis, the negative comments from landfill opponents do not accurately portray the GHG emissions from landfills in the United States, and data are often misused to suggest that landfills are collecting far less of the LFG than actually is occurring nationwide and that waste should therefore be diverted from landfills. As such, prior to discussing the specific misinformation presented by landfill opponents, it is important to recognize certain facts about landfills in United States:

- The United States has a very stringent level of regulation with regard to LFG and has the highest percentage of landfills with LFG collection systems relative to any other country worldwide. Specifically, the landfill New Source Performance Standards (NSPS) under 40 Code of Federal Regulations (CFR), Part 60, Subpart WWW, state and local regulations that go beyond the NSPS, and LFG requirements under Resource Conservation and Recovery Act (RCRA) Subtitle D require LFG collection and control at the majority of landfills in the U.S., including the largest landfills in the country.

- Because of regulatory as well as other programs that promote LFG recovery and utilization, such as the USEPA Landfill Methane Outreach Program (LMOP), landfills in the United States have the highest percentage of LFG capture worldwide. As reported by Themelis (2007, 2008), approximately 60% of the worldwide capture of methane occurs in the United States even though the U.S. only generates 24% of the worldwide methane.

- The reduction in landfill GHG emissions are due to stringent air regulations in the U.S. and improved practices in LFG collection since the early 1990s. The data collected by USEPA for all U.S. landfills demonstrate that the landfill NSPS rule has been a huge success in reducing GHG emissions from landfills and that additional reduction, if needed, should be based on similar command and control regulations for LFG collection and control that expand upon past successes.

- Due to these efforts, landfills are the only major industry sector with declining GHG emission since 1990 despite increases in waste disposal (USEPA, 2009a). By USEPA statistics, landfills have reduced GHG emissions by almost 15% between 1990 and 2008, the most recent inventory year (USEPA, 2010). This is despite managing 24% more refuse since 1990 (EPA, 2009b). Few, if any, industries can demonstrate similar GHG reductions despite increases in production and throughput over this time period.

- The most recent solid waste report from the IPCC (2006) on global landfilling states that "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%." This statement has been commonly misused in an attempt to support a position that the lifetime collection efficiency for U.S. landfills is only 20%. The 20% capture rate is not representative of landfills in U.S. The value is clearly defined by IPCC as the low end (that is, "may be as low as") of gas capture, and the United States is clearly not on the low end of LFG collection due to our extensive regulatory program for LFG control as noted above. In fact, the United States has been at the high-end of LFG collection efficiencies since the advent of regulatory programs in the country. As noted by the same IPCC report, ">90% recovery can be achieved at cells with final cover and an efficient gas extraction system." This >90% recovery estimate is based on intensive field studies of the methane mass balance at regulation landfills with final cover found in the United States (IPCC, 2006) while the 20% value is only an estimate to be applied globally.

- A certain amount of methane oxidation occurs in various types of landfill covers, including simple soil covers, and converts a portion of the anthropogenic methane into biogenic carbon dioxide. Current literature support methane oxidation rates at levels above the 10% default value used by USEPA (2009a) and IPCC (2006). Recent research data suggest that the default value may be understated and that methane oxidation in landfill covers may be considerably higher, depending on the cover type and other conditions (Chanton, et al., 2009). The use of more accurate and up-to-date methane oxidation values for landfill covers may reduce methane emissions further from those estimated by USEPA (2009a) and IPCC (2006). Bogner, et al. (2007) has reported that "under circumstances of high oxidation potential and low flux of landfill methane from the landfill, it has been demonstrated that atmospheric methane may be oxidized at the landfill surface." This study demonstrates that even when methane escapes a gas collection system, the ability of the landfill cover to oxidize methane can actually result in no or little net emissions.

- Currently and since 1998, if carbon sequestration is considered for landfills, the amount of carbon sequestered each year can offset the net methane emissions from landfills as detailed by USEPA (2006) and Weitz, et al. (2002). The latter stated that "when the consideration of carbon storage is included in the calculations, it dramatically offsets all of the energy and landfill emissions." USEPA has drawn similar conclusions (USEPA, 2006). Bogner, et al. (2007) stated that "since lignin is recalcitrant and cellulosic fractions decompose slowly, a minimum of 50% of the organic carbon landfilled is not typically converted to biogas carbon but remains in the landfill. Carbon storage makes landfilling a more competitive alternative from a climate change perspective, <u>especially where landfill gas recovery is combined with energy use</u>." (emphasis added)

Despite the progress made in capturing LFG, methane emissions from landfills can be further reduced by regulations or incentives that will result in additional LFG capture and utilization by means of:

- Improving the design and construction of the LFG collection system to improve efficiencies,
- Increasing LFG collection system efficiencies by improved cap and cover systems.
- Promotion of earlier installation of gas collection systems.

It is these types of improved control measures that should be the focus of efforts to further reduce methane emissions from landfills, including any incentives, financial or otherwise, that encourage more and earlier LFG collection as well as the beneficial use of the collected LFG to create additional GHG reductions by generating renewable energy.

Organics diversion, composting, and/or other waste management options, which are sometimes viewed as alternatives to landfills, are more properly considered as additional waste management tools that can be employed <u>in combination</u> with best practices at landfills to manage refuse. All such practices must be judged on their own merits, including cost-effectiveness, environmental impacts and operational efficiency, and not on the back of unfounded negative statements about landfills or other management options. Control of methane emissions at landfills, or any method that lessens release of GHG or decreases the carbon footprint, should not be opposed because it would result in alternative management methods, such as composting, appearing less attractive.

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2.0 LANDFILL GAS COLLECTION EFFICIENCY

2.1 BACKGROUND

Landfill gas (LFG) collection or capture efficiency is the amount of LFG that is collected relative to the amount generated in a landfill. The United States Environmental Protection Agency (USEPA), state, and local regulators often use assumed gas collection efficiencies to calculate landfill emissions for regulatory and other purposes. USEPA's AP-42 document (USEPA, 1997) provides an efficiency of 75% (as a conservative default value from a range of 60 to 85%) USEPA derived this default collection or capture efficiency value from a literature review and compilation of estimates made by various practitioners in the LFG industry, rather than from field test data (Leatherwood, 2002).

LFG system owners and operators believe that collection efficiencies, from capped landfills that are provided with adequate LFG collection systems, can be greater than 75% ; also, that the requirement to use default values for regulatory purposes creates disincentives for owner/operators to endeavor to achieve higher collection efficiencies because those efforts would not be recognized. On the other hand, opponents of landfills believe that actual collection efficiencies are much lower than the regulatory default values and often incorrectly cite the Intergovernmental Panel on Climate Change (IPCC) value of 20%, which represents the low-end of lifetime average collection efficiencies for international greenhouse gas (GHG) inventories for landfills (IPCC, 2006).

While a variety of experts, including those involved with development of the IPCC methodologies, have proffered opinions about LFG collection efficiencies based on theoretical analyses, few quantitative estimates of LFG collection efficiency have been developed until quite recently.

2.2 MEETING OF SENIOR RESEARCHERS AND MANAGERS ON CLIMATE IMPACTS OF THE U.S. WASTE MANAGEMENT INDUSTRY

The subject meeting was organized by the Earth Engineering Center and the Energy Recovery Council and occurred in Washington, D.C., on Wednesday, January 28, 2009. One of the objectives of this meeting was to agree upon data and information disseminated to the public regarding waste management with regard to the GHG footprint of the U.S. waste management industry.

The consensus reached at this meeting was that the percent recovery of LFG in a landfill is site-specific. The range of LFG recoveries expected are shown in Figure 2.1 (presentation by Prof. Morton Barlaz of North Carolina State University) and the values developed by the Solid Waste Industry for Climate Solutions (SWICS, 2009), which are further discussed in this section.

Weighted Average Collection Efficiency (%)

		Decay Rate (yr^{-1})				
		0.02	0.04	0.07	0.1	0.15
Year of 95% gas production	Gas Collection Scenario	>100	76	44	31	21.5
Case 1 AP-42	Years 0 – 100: 75%	75	75	75	75	75
Case 2 Phased in collection	Years 1-2: 0% Year 3: 25% Year 4: 50% Years 5-100: 75%	70.9	67.9	63.3	NA	NA
Case 3 Typical operating scenario	Years 1-2: 0% Year 3: 25% Year 4: 50% Years 5-10: 75% Years 11-100: 95% (99%)	86.9 (90.1)	81.5 (84.2)	73.6 (75.7)	NA	NA
Case 4 Worst case NSPS	Years 0 – 5: 0% Years 6 – 100: 75%	67.6	62.5	54.9	NA	NA
Case 5 Bioreactor Typical operation	Years 1-2: 25% Year 3: 35% Year 4: 60% Years 5-10: 75% Years 11-100: 95% (99%)	N/A	N/A	77.2 (79.3)	71.6 (73.2)	64.2 (65.1)

Figure 2.1 (Prof. Morton Barlaz presentation). LFG Collection Efficiency in Landfills Provided with LFG Collection Equipment, Under Different Operating Scenarios

The SWICS-derived collection efficiency values are listed below (SWICS, 2009):

- 50-70% (mid-range default = 60%) for a landfill or portions of a landfill that are under daily soil cover with an active LFG collection system installed;

- 54-95% (mid-range default = 75%) for a landfill or portions of a landfill that contain an intermediate soil cover with an active LFG collection system;

- 90-99% (mid-range default = 95%) for landfills that contain a final soil and/or geomembrane cover systems with an active LFG collection system.

Note that the mid-range default values developed by SWICS for the three cover types indentified above were adopted by USEPA as part of its mandatory GHG reporting rule.

During the building up of a landfill cell (first two to five years), there may be no methane recovery, unless the cell is provided with horizontal pipes for gas collection and/or the leachate collection and removal system (LCRS) is equipped and used for gas recovery. After capping, landfills that are provided with well-maintained gas collection equipment can attain 95% methane capture. Figure 2.2 (presentation by N.J. Themelis, Earth Engineering Center) shows the expected lifetime LFG recovery from various types of landfills.

Capture and loss of methane from various landfills
for assumed ultimate maximum generation of methane: 70 Nm3/U.S. ton)

Type of Landfill	Nm3 CH4 captured	Nm3 CH4 lost to atmosphere
LF cell capped two years after start up	63	7
LF cell capped five years after start up	53	17
LF cell not provided with LFG capture	0	70

Figure 2.2 (Themelis, 2009): Estimated Lifetime LFG Capture from Landfills with and without LFG Capture Equipment

2.3 REVIEW OF LITERATURE ON LFG CAPTURE

The only way to rigorously quantify the LFG/methane collection efficiency is to have a measure of collected methane and fugitive methane emissions from the same landfill area at the same time. While measures of collected methane are readily available, measures of fugitive emissions are considerably more difficult to obtain and have only been reported for a few landfills. SWICS (2009) compiled data on field studies of methane flux where collection efficiency was or could be calculated and presented these in an industry guidance document. The numeric values for collection efficiency put forth by SWICS were recently adopted by USEPA in its mandatory GHG reporting rule under 40 Code of Federal Regulations (CFR), Part 98, Subpart HH.

As detailed in SWICS (2009), 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 Montreuil-sur-Barse Landfill testing included two cells filled from 1994 to 1999 with about 9700 metric tons of waste in place, one with a final clay cover and one with a geosynthetic clay liner (GCL). The Lapouyade Landfill testing included three cells operating since 1996 and tested in 2000 and 2001 with about 145,000 metric tons of waste in place, one with a final clay cover and two with temporary clay covers. The Grand'landes Landfill testing included two cells operating from 1989 through 2001 with about 108,000 metric tons in place, one with a final clay cover and one with a final geomembrane cover with horizontal gas collectors under the cover. The collection efficiency was calculated as the ratio of recovered gas to empirically modeled gas generation. Specifically, Spokas et al. used the following equation:

CH_4 generated = CH_4 emitted + CH_4 oxidized + CH_4 recovered + CH_4 migrated + Δ CH_4 storage

Methane generation was estimated from a gas production model. Emitted methane was measured by using either static chambers or an atmospheric tracer technique. Methane oxidation was measured by using a stable isotope technique that provides a conservative estimate of oxidation. Recovered methane was based on direct measurements at each landfill, and methane migration was based on calculations of methane diffusion through liners. Maximum potential methane storage was calculated from an estimate of waste porosity and changes in methane concentration and used as an upper limit of the value required to close a mass balance. For this report, the data were recalculated where collection efficiency was defined as:

$$\frac{\text{methane collected}}{\text{methane collected + emissions + oxidation + migration}} \qquad (1)$$

The results are summarized in Table 2-1. As presented, collection efficiencies for final clay covers were uniformly greater than 90% while the collection efficiency for the temporary cover was slightly greater than 50% in the summer but more than 90% in the winter. Collection efficiencies were then recalculated to be consistent with other literature, which exclude the oxidation and migration terms that can introduce more uncertainty. The difference between equations 1 and 2 is minor in consideration of the uncertainty of these types of studies.

$$\frac{\text{methane collected}}{\text{methane collected + emissions}} \qquad (2)$$

Borjesson, et al. (2007) reported on methane oxidation and gas collection at six Swedish landfills using Fourier-transformed infrared (FTIR) in combination with a tracer. While the emphasis of their study was on methane oxidation, sufficient data were published to calculate collection efficiency as in Equation 2. Data from two of the landfills (Hagby and Visby) were excluded from this review because it was reported that the gas collection system was not working during the test period. The results for each landfill test are presented in Table 2-2. All landfills reported were active and only minimal information was reported on the cover type.

Cover Type	Collection Efficiency (%)a	Collection Efficiency (%)b
Final clay cover (1 meter) with LFG recovery	91.5	92.6
Final geosynthetic clay with LFG recovery	51.5	53.0
Final clay cover (1 meter) with LFG recovery – summer	90.7	92.9
Final clay cover (1 meter) with LFG recovery – winter	97.8	98.6
Thin clay temporary cover (30 cm) with LFG recovery – summer	53.9	54.7
Thin clay temporary cover (30 cm) with LFG recovery – winter	93.2	95.1
Final clay cover (1 meter) with LFG recovery	99.2	100
Final geomembrane with horizontal gas collection	98.1	99.2

a. Calculated as methane collected/(methane collected + emissions + oxidation + migration)
b. Calculated as methane collected/(methane collected + emissions)

Table 2.1. Collection Efficiency for Various Covers Reported in Spokas et al. (2006)

Cover Type	Collection Efficiency (%)a
Fiborna (wood chips and sludge)	68.4
Fiborna (wood chips and sludge)	65.0
Fiborna (wood chips and sludge)	70.0
Heljestorp (sewage sludge and soil)	57.8
Hogbytorp (sewage sludge and soil)	33.9
Hogbytorp (sewage sludge and soil)	43.2
Sundsvall (sewage sludge and soil)	63.3

a. Calculated as methane collected/(methane collected + emissions)

Table 2.2. Collection Efficiency for Various Covers Reported in Borjesson, et al. (2007)

Mosher et al., (1999) reported a summary of methane emissions from nine landfills in the Northeastern United States where emissions were measured by both static chambers and a tracer flux technique. Two of the landfills collected gas, making it possible to compare emissions to collected gas. One of the two landfills was closed and had a geomembrane plus soil cover. A collection efficiency of 90.5% was calculated as in Equation 2. The authors indicate that the gas collected was not measured accurately, which casts some doubt on this value. This collection efficiency is nonetheless likely to be reasonable from two perspectives. First, this landfill had the lowest emissions of the sites studied and second, the collection efficiency is consistent with other values in this review. A collection efficiency of 70% was calculated for an active landfill in which part of the landfill was covered with a geomembrane but other parts had daily cover only.

Huitric and Kong (2006) reported collection efficiencies for the Palos Verdes Landfill (PVLF) in Los Angeles County. The PVLF was closed in 1980, has a five-foot thick clay cap and an active gas collection system. Gas emissions were measured using an SEM-500 flame ionization detector (FID) monitor. An "integrated surface methane" (ISM) concentration was measured by surface scans at 3 inches above the surface after dividing the landfill into approximately one acre grids. The measured ISM was compared to the ISM that was calculated using the USEPA's Industrial Source Complex (ISC) air dispersion model. The calculated ISM assumes no gas collection, and the source term was based on the volume of collected gas at the PVLF. Collection efficiency was calculated as follows:

$$\frac{ISM_r}{(ISM_r + ISM_e)} \qquad (3)$$

where ISM_r is the modeled reduction in surface emission due to collection and ISM_e is the measured surface methane concentration due to emissions.

In this method, emissions due to methane oxidation are incorporated into the measured ISM. This calculation assumes that methane concentration is correlated to flux. The efficiency of the LFG collection system at the PVLF was calculated to be 94 to 96%. In Huitric et al. (2007), the collection efficiency determined using Equation 3 was supported by the results of a static flux chamber study completed at the PVLF under the direction and approval of the California

Department of Toxic Substances Control (DTSC). In fact, even higher collection efficiencies were reported for the PVLF when using flux chamber results, approaching 100%.

Lohila, et al. (2007) reported methane fluxes for a section of a Finnish landfill that included an active disposal area and a sloped area. The active area was covered daily with soil and construction and demolition waste rejects, and the sloped area had a cover that included 0.2 to 0.5 meters of compost over 0.5 to 2 meters of diamicton and clay. Three estimates of collection efficiency were reported. First, it was reported that the mean methane flux over seven days was reduced by 79% when the gas collection system was turned on. This measurement was made by using methane concentration data coupled to an eddy covariance method. Another estimate was made by comparing the mean methane emission to the volume of gas collected and assuming that methane production was the sum of emissions plus collection. This resulted in an estimate of 69% collection efficiency at the Finnish landfill.

2.4 COLLECTION EFFICIENCY VALUES PROVIDED IN THE LITERATURE

Based upon review of the research studies regarding this issue, LFG collection efficiencies for landfills with different types of cover and active LFG collection systems are presented in the bullets below (SWICS, 2009):

- 50-70% (mid-range default = 60%) for a landfill or portions of a landfill that are under daily soil cover with an active LFG collection system installed;
- 54-95% (mid-range default = 75%) for a landfill or portions of a landfill that contain an intermediate soil cover with an active LFG collection system;
- 90-99% (mid-range default = 95%) for landfills that contain a final soil and/or geomembrane cover systems with an active LFG collection system.

Note that the mid-range default values for the three cover types indentified above were adopted by USEPA as part of its mandatory GHG reporting rule, which gives strong credence that these values are representative of landfills in the United States (40 CFR, Part 98, Subpart HH).

2.5 WHY IPCC 20% CAPTURE EFFICIENCY DOES NOT APPLY TO U.S. LANDFILLS EQUIPPED FOR LFG RECOVERY

The most recent IPCC guidance on landfills (IPCC, 2006) states that "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%." This statement has been improperly cited by landfill opponents in an attempt to support a position that the lifetime collection efficiency for U.S. landfills is only 20%. To clarify, the 20% value quoted by the IPCC represents a global average, not a U.S. average. There are numerous inaccuracies associated with this position, and actual data and analysis clearly demonstrated that the 20% value has no relevance for landfills in the U.S.

The 20% value may be reasonable as a global measure of the percentage of the worldwide generated landfill methane that is being collected. The lifetime capture rate of 20%, as quoted by the IPCC, is representative of all landfills around the world, where many landfills are not designed or operated consistent with U.S. standards for sanitary landfills. The majority of the landfills not designed to U.S. standards for sanitary landfills also have no LFG controls. There are also only a small number of landfills with any controls at all, and where existing LFG systems are in place, they are generally are only partial systems as compared to U.S. standards.

The 20% capture rate is not representative of landfills in U.S. for the following reasons. The value is clearly defined as the low end (i.e., "may be as low as") of worldwide landfill gas capture, and the United States is clearly not on the low end of LFG collection worldwide. As reported by Themelis (2007, 2008), the U.S. collects approximately 60% of all LFG currently recovered worldwide, even though the U.S. only generates 24% of the worldwide methane. By any measure, U.S. landfills are not on the low end of the global gas capture scale.

The 20% value in the IPPC document is based on research completed by Oonk and Boom (1995) on several Dutch landfills. Oonk and Boom clearly state that the 20% value is based on "the amounts of LFG that are recovered for economic reasons" not on LFG collection required by regulatory standards. Oonk and Boom further conclude that "it should be noted, that many Dutch landfill recovery projects in practice, do a lot better than the situation described above [*20% value based on economic drivers*]. This is because emission reduction is also the main objective in these landfill gas projects. This emission reduction is in most cases related to odor nuisance or vegetative changes." This clearly shows that the 20% value has no relevance for regulated landfills in the U.S., whose primary function is emission reduction due to regulatory drivers.

Oonk and Boom's final conclusions are that "recovery has to be looked upon more as a means for reducing emissions" and that "the policy should be to recover the maximum recoverable amount of landfill gas, utilize what is economically attractive to utilize, and flare the surplus." which is exactly what occurs in the U.S.

In addition, the same IPCC report also says that ">90% recovery can be achieved at cells with final cover and an efficient gas extraction system. This 90% capture rate is based on intensive field studies of the methane mass balance at landfills, as detailed above, while the 20% value estimated for the low-end capture is only an estimate.

Further, the U.S. has the most comprehensive requirements for LFG collection and control in the world as accomplished through the landfill New Source Performance Standards (NSPS) under 40 CFR, Part 60, Subpart WWW as well as more stringent state and local regulations like those in California. These regulations prevent excessive fugitive emissions from landfills by requiring collection of LFG and destruction of the collected methane and other organics as well as extensive monitoring for surface emissions of methane to ensure LFG capture is maximized. These regulations also dictate specific requirements for how comprehensive LFG systems must be designed and operated. No other country comes close to the U.S. standards.

The NSPS requirements are for new and modified landfills designed to hold 2.5 million megagrams (2.755 million tons) and 2.5 million cubic meters (3.27 million cubic yards) or more of waste over their lifetime and that could emit greater than or equal to 50 megagrams (Mg) per year of non-methane organic compounds (NMOC). Some smaller landfills are not required to comply with this NSPS rule because smaller landfills do not emit near as much NMOCs as the larger landfills. However, in some jurisdictions, smaller landfills are required to install controls due to state and local regulations such as California's Assembly Bill 32 landfill methane rule, which will require landfills as small as 450,000 tons in place to install gas capture systems.

Since 1992, U.S. landfills have also installed and operated LFG collection systems to comply with Resource Conservation and Recovery Act (RCRA) Subtitle D requirements. RCRA Subtitle D facilitates/requires landfills to control LFG migration as well as prevent off-site odor impacts and groundwater impacts. U.S. landfills also install LFG collection systems to support LFG recovery and beneficial use projects. Finally, the U.S. has an active carbon credit trading market with landfill methane reduction projects representing the largest percentage of projects where verified carbon credits have been issued (Climate Action Reserve [CAR], 2010).

All told, there are numerous regulatory and non-regulatory drivers that lead to the installation and operation of LFG collection and control systems in the U.S., and to the U.S. achievement of the highest degree of LFG collection worldwide. As such, it can be clearly seen that the 20% value suggested by IPCC, and misquoted by the landfill opponents, is neither representative of nor reasonable to ascribe to U.S. landfills. As illustrated previously in Figure 2.1, Barlaz, et al (2009) reported collection efficiencies for U.S. landfills, ranging from 50% to 100%, based on various field studies. In the Barlaz study, lifetime collection efficiency values, estimated on a 100-year basis, for NSPS-regulated landfills ranged from approximately 55% to 68% for the worst-case NSPS situation (sites that wait the full 5 years prior to gas collection), improving to approximately 79% to 85% for aggressively controlled sites.

2.6 LFG EMISSIONS AFTER CLOSURE

Landfill opponents suggest that some time after closure, LFG generation could increase again if liquids are allowed to infiltrate into the refuse mass, resulting in LFG generation rates that are equal to or greater than the peak rate, which typically occurs one year after closure. This is an outrageous statement, far divorced from fact, and simply not supported by the available data on any landfill. The landfill industry knows of no such instances where this phenomenon has occurred, and landfill opponents suggesting this phenomenon have cited no references or examples of its existence. It is well known and recognized that LFG generation rates will decrease over time to eventually insignificant levels and that the maximum LFG generation rate occurs at or within two years of closure.

According to USEPA's LFG emissions model (LandGEM) (USEPA, 1997), gas generation resembles a bell curve as shown in Figure 2.3 below.

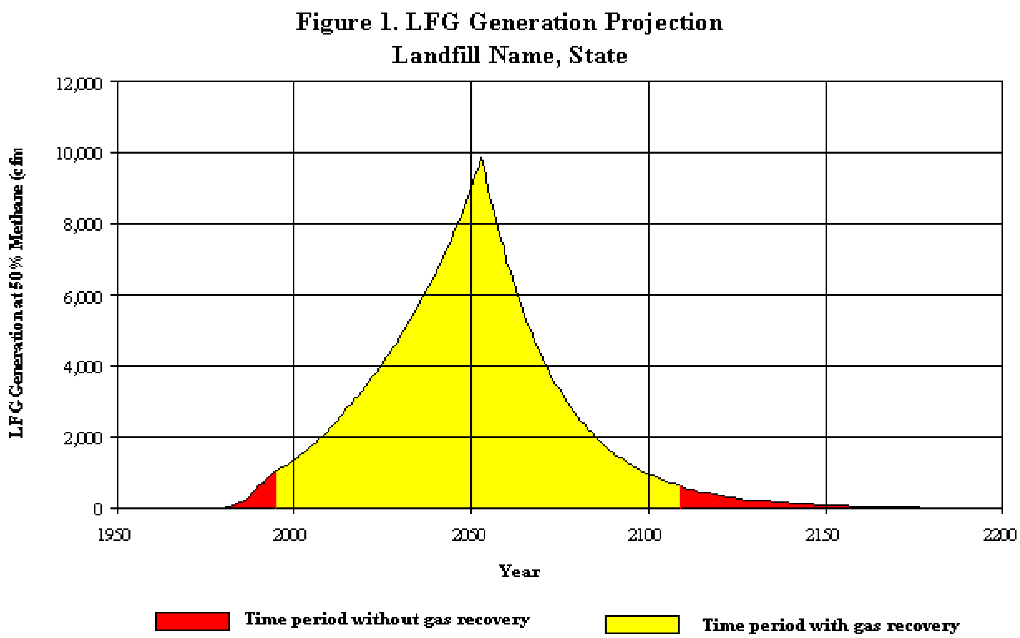

Figure 2.3. Example LFG Generation Projection
Landfill Name, State

LandGEM is based on a first-order decomposition rate equation for quantifying emissions from the decomposition of landfilled material in municipal solid waste (MSW) landfills. The first-order decay model is also used by IPCC and is the standard and accepted technique for estimating LFG generation. During the early and late phases of a landfills lifetime, LFG generation is at its lowest, as shown on the figure. The majority of LFG produced occurs during the active phase of the landfills lifetime, during the time when LFG collection would occur, and in the U.S., would be required to occur. LFG generation decreases after the landfill is closed, as shown at the peak of the graph, which occurs the year after closure.

The NSPS requires landfills to install LFG collection system within two to five years of the initial placement of the first ton of waste in the landfill (or new landfill cell) after the NMOC concentration of the emissions reaches above 50 Mg per year. The system may be removed when the NMOC concentration drops below the threshold of 50 Mg on three successive test dates, but only after a minimum of 15 years of operation and assuming there are no other regulatory or energy recovery reasons to keep the system operating. Since the landfill is not generating as much LFG by volume and methane by mass during these uncontrolled time periods (shown in red in the area under the curve), it can be assumed that the largest majority of the generated methane will be collected and controlled and that only limited methane emissions will occur during periods of uncontrolled LFG emissions. The same downward trend after closure exists for all pollutants carried by the LFG, including non-methane organic compounds (NMOCs) and toxics in the LFG. During these limited uncontrolled periods, much of the fugitive methane emissions are oxidized by the cover materials since oxidation is at its greatest when gas production resulting methane flux is at the lowest (Bogner, et al., 2007).

In fact, Bogner, et al., (2007) have reported that "under circumstances of high oxidation potential and low flux of landfill methane from the landfill, it has been demonstrated that atmospheric methane may be oxidized at the landfill surface. In such cases, the landfill cover soils function as a sink rather than a source of atmospheric methane." Schuetz et al. (2003) also reported that "…landfill soil covers show a significant potential for methane oxidation and co-oxidation of NMOCs. Under certain conditions, landfills may even function as sinks of both methane and selected NMOCs including aromatic hydrocarbons and lower chlorinated compounds." This research demonstrates that even when methane escapes a gas collection system, the ability of the landfill cover to oxidize methane can actually result in no or little net emissions.

Some of the oldest landfills in the U.S. (including those that have been closed and capped for more than 50 years) continue to generate LFG following the curve predicted by the first-order decay model---i.e., less gas is available for recovery each successive year. None of these sites have experienced even a small increase in gas production well into their post-closure lifespan. Examples of this situation can be found throughout the Los Angeles area where the local LFG rule requires LFG systems at many smaller and older landfills. Some of these sites have been redeveloped into golf courses and parks where the surface is actually irrigated well after closure. Even with this irrigation, there have been no increases in gas generation/recovery after closure, and the landfills continue to be able to meet the stringent surface emission limits in the South Coast Air Quality Management District (SCAQMD) Rule 1150.1. There is no real world evidence of the phenomenon suggested by opponents of a second peak of gas generation 40 or more years into post-closure.

Opponents' argument that landfills will experience an additional peak of LFG generation far into the post-closure period of the landfill is predicated on the concept, and not on measurement or data, that all landfill cover systems will ultimately fail and after failure, additional moisture will infiltrate into the waste resulting in a new increase in gas production. This argument is flawed in many ways not the least of which is the fact that there is no evidence of landfill covers failing in United States to any substantial degree as detailed below.

2.7 LANDFILL COVER SYSTEMS

Landfill covers are barriers comprised generally of clay/soil caps, mostly with vegetation. The vegetation prevents erosion of the cap, and there is no evidence that these caps degrade substantially over time to the degree necessary to allow massive infiltration of liquids. Even synthetic caps have additional soil layers that would remain intact even under the highly unlikely scenario that there was failure of the primary cap. Further, at and throughout closure, landfill surfaces are graded to drain rainwater away from the landfill, which would further prevent water infiltration.

Failure of a final landfill cap also is unlikely because Resource Conservation and Recovery Act (RCRA) regulations require the landfill owner/operator to maintain the final cover during the lengthy post-closure maintenance period. The regulatory requirements that set forth when the landfill operator may be released from post-closure maintenance responsibilities are designed to ensure the landfill's potential to affect the groundwater and to generate LFG is no longer significant.

Although some have posed concerns about final cover system failure, this is unlikely as evidenced by low to negligible leachate generation rates and continually downward trends for leachate generation observed at modern MSW landfills currently in post closure care. Further, the expected service life of a geomembrane barrier layer in a composite cover system is on the order of 1,000 years, comparable to the long-term performance of geomembrane barrier materials in liner systems. Similarly, whether in combination with an upper geomembrane component or as a single-layer cover system, a low-permeability composite clay liner provides an excellent long-term and robust barrier to precipitation.

Investigations of landfill covers and environmental protection systems following a severe natural event suggest that landfills are highly resistant to damage from such events. Studies performed after the Florida hurricanes of 2004 (Roberts, et al, 2005), the Northridge and Loma Prieta earthquakes in California (Matasovic & Kavazanjian, 1998), and the San Diego wildfires of 2003 showed that the integrity of landfills had not been compromised. The only damage that occurred was to surface features such as vegetation and LFG vents that were repaired at minimal cost. In reviewing the literature, no evidence was found of an extensive landfill failure resulting from a naturally occurring and potentially damaging emergency situation.

Manmade emergencies, while more common than natural disasters, are similarly rare at landfills. Blight (2008) examined six of the largest landfill failures that occurred worldwide as a result of human error in the 28-year period from 1977 to 2005. None of these major failures occurred in the United States, which can be largely attributed to the regulation of solid waste landfills at the state and federal level. Of the six landfills studied, four occurred in unmanaged dumps that had apparently not been subject to geotechnical analysis during the design stage. The remaining two occurred in engineered landfills whose causes were later investigated and well understood – inadequate design and operation in consideration of liquid waste and moisture conditions – and entirely avoidable.

In their research report for the USEPA (2002), Koerner & Hsuan (2002) selected a 50% degradation level as an endpoint for the study of cover systems, although they note that even with this reduction in design property the geomembrane can still function, albeit at a decreased performance level. With this conservative endpoint defined, the service life of high-density polyethylene (HDPE) geomembranes was estimated to be on the order of a thousand years: approximately 200 years for antioxidant depletion, over 20 years for induction of geomembrane oxidation, and 750 years for 50 percent degradation of strength properties (Bonaparte, et al., 2002a).

Covers at RCRA Subtitle D landfills consist of a low-permeability barrier layer (e.g., a geomembrane or a compacted clay layer, CCL) overlain by a vegetative soil cover layer. Due to its excellent durability, linear low-density polyethylene (LLDPE) geomembrane is the most common type of geomembrane barrier used in final cover systems. Laboratory results suggest that it will take approximately 200 years for the antioxidants in LLDPE geomembrane to be "depleted" and another 800 years for the geomembrane strength properties to be reduced by 50 percent. Even with this loss in strength properties, the LLDPE geomembrane is expected to function adequately as a barrier.

An increasing number of landfills are being closed with an evapotranspirative (ET) final cover system (i.e., all-soil covers) rather than a prescriptive final cover system with a CCL/geomembrane barrier. The concern is that a CCL barrier will desiccate in arid and semi-arid climates if not protected by an overlying geomembrane and a sufficiently thick soil erosion layer. An ET final cover typically consists of more loosely compacted soils of sufficient thickness to optimally store and release water through ET processes.

For example, when ET covers are constructed with surficial site soils, their long-term performance can be inferred by observation of vegetation and precipitation recharge conditions at the site. The studies referenced above demonstrate that such cover systems can have service lives that exceed 1,000 years with minimal maintenance and still satisfy the performance criteria of infiltration control (Bonaparte, et al., 2002b).

2.8 LFG EMISSIONS PRIOR TO LFG COLLECTION

Landfills are criticized as emitting substantial methane emissions before LFG collection systems are employed. The argument assumes organic wastes produce methane very quickly before LFG collection is operating, daily cover of waste does not retard emissions, and methane from waste is not collected for five years after placement. Critics claim that LFG collection systems do not operate to collect emissions from all waste until five years after placement. This assumption is based on a misreading of the federal NSPS standards that provide that waste areas must be subject to collection systems within five years of opening the area, unless shorter periods apply.

In fact, most waste is under emission control much earlier than claimed by critics. NSPS rules require LFG collection within two years after the first waste placed in a landfill reaches final grade; therefore, for many landfill areas, all waste is subject to LFG collection within two years. Further, the five-year LFG installation compliance clock begins when an area opens to accept waste. Areas are open for many years, subjecting waste placed later in an area to a shorter period of time before LFG collection begins.

According to Themelis (2009; Figure 2.4), 66% of the waste disposed in U.S. landfills and monitored by USEPA is placed in landfills with active gas collection systems in place. Therefore, many of the new disposal cells overlay and/or are adjacent to areas that already have collection and control of LFG. In addition, cover practices for U.S. landfills require the refuse to be covered with daily cover at the end of a working day; in effect, no waste is left for more than 24 hours without cover per federal and state regulations. Surface emissions monitoring data from the SCAQMD Rule 1150.1, that requires monitoring of all landfill surfaces, regardless of waste age, have shown no appreciable difference in emissions for the active face of the landfill where recent disposal has occurred versus other areas under intermediate cover with active collection.

SUR Analysis of EPA Database of operating U.S. Landfills

MSW landfilled annually *(1052 landfills)*	MSW landfilled annually in landfills that recover LFG *(376 landfills)*	LFG captured in 2006	Average LFG captured per ton MSW at landfills that recover LFG
189 million tons*	125 million tons	7800 million Nm3	62 Nm3/ton (Nm3: standard cubic meters of LFG)
100%	66%		

*vs 266 million tons landfilled as per BioCycle/Columbia survey[3]

Figure 2.4. U.S. Landfills Collecting LFG (Themelis, 2009)

Depending on the type of waste, moisture content of the waste, cover properties, and other criteria, it can take anywhere from several months to several years for waste to reach the methanogenic phase of LFG production. As such, methane generation is not immediate. Even for bioreactor landfills where gas production is maximized, USEPA, after reviewing the available data, concluded in the landfill National Emission Standards on Hazardous Air Pollutants (NESHAPS; 40 CFR Part 63, Subpart AAAA) that gas collection at bioreactor landfills is only necessary by six months after achieving bioreactor status (40% moisture). For conventional landfills, this time window may be as long as three to five years before measurable gas production begins, depending on the site-specific conditions, particularly for dry climate landfills.

Finally, the research on methane oxidation, as summarized by SWICS (2009) and Chanton (2009), demonstrate that daily covers soils oxidize methane to a greater degree than many low permeability final cover soils, with research suggesting values form 20 to 55% for soil covers. Biocovers used as alternative daily covers (ADCs) have been shown by Abichou (2004) and others to have even greater methane oxidation potential than soil covers, including values greater than 55%. Daily cover, particularly biocovers, reduces emissions of organic compounds including methane.

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3.0 LANDFILL GAS TO ENERGY

3.1 BACKGROUND

Landfills are continuously producing and recovering landfill gas (LFG). Energy recovered from methane generated at a landfill displaces energy that is produced from fossil fuels, among other conventional sources of electricity. This well-recognized fact has led to widespread support for LFG-to-energy (LFGTE) projects. Support stems from the view that replacement of fossil fuels by renewable energy is beneficial to public health, the environment and national security. Some landfill opponents suggest that recovering and beneficially using LFG should be somehow curtailed or stopped, because using waste to generate energy makes landfills more environmentally sound and less able to be criticized, is simply irresponsible and devoid of fact.

Energy needs in the United States (U.S.) in the near future will be greater than the nation can provide with our current fossil fuel supplies and technology for power generation, according to the North American Electric Reliability Corporation (NERC) (NERC, 2007). In 2007, NERC has stated that electrical utilities have forecasted the demand to increase (from 2006) by 19 percent (141,000 Megawatts, MW) in the U.S. over the next ten years, but project committed resources to increase by only 6 percent (57,000 MW) during the same timeframe (NERC, 2007). This leaves a deficiency in power supply over the next 10 years of 84,000 MW. LFGTE can play an important role in offsetting this deficiency while reducing reliance on fossil fuel-derived sources of electricity.

According to the U.S. Environmental Protection Agency (USEPA) Landfill Methane Outreach Program (LMOP), there are currently more than 509 LFGTE projects generating approximately 1,563 MW (USEPA, 2010), which represents an increasing trend in LFGTE projects throughout the U.S. The benefits of LFG recovery for energy include reduction of greenhouse gas (GHG) emissions through both direct reductions and avoided emissions as well as the displacement of fossil fuel usage. The current drivers for energy recovery from LFG include tax credit and utility pricing incentives as well as more recent incentives for renewable energy, green power, and GHG reduction credits.

In 2002, the U.S. population was approximately 281 million people. During that same year, 369 million tons of municipal solid waste (MSW) was generated, resulting in a per capita generation rate of 1.31 tons. By 2006, the generation of MSW in the U.S. had increased to 413 million tons of MSW, corresponding to 1.37 tons per capita (Arsova et al, 2008). Despite intense efforts for waste reduction and recycling, the amount of MSW that had to be landfilled in 2006 was substantially higher than in 2002 (Arsova et al, 2008). This trend emphasizes the need for increased support for LFGTE projects because as long as the U.S. population continues to increase, the need for landfill disposal will increase, regardless of strong and hopefully successful efforts for source reduction, recycling, and waste combustion.

With the advent of both legislation and technology, recycling, including composting, accounted for the fate of 29% of the MSW generated in 2006 (Arsova et al, 2008), as compared to a 1994 level of 23% (Simmons, et al., 2006). That is a modest increase in recycling over a 15-year period, which reflects the difficulty in achieving high rates of recycling. The BioCycle/ Columbia University survey of 2006 national data, (Arsova et al, 2008) showed that 28.6% of the MSW was recycled, 6.9% was combusted with energy recovery, and the bulk of it (64.5%) was landfilled. Landfills remain the primary method for disposal of MSW in the U.S., and there is no indication that this will change in the foreseeable future. Other methods of MSW management (such as recycling, composting, waste-to-energy, anaerobic digestion, and conversion technologies) are most often more costly than landfill disposal on a per ton disposed basis, making landfilling the most cost-effective method for managing MSW.

As population and landfill disposal increase, the generation of LFG will also increase. MSW in landfills either degrades to produce methane that can be recovered as renewable energy or is sequestered as carbon. Therefore, landfills are an important part of the global carbon cycle as well as an important part of the program to meet the nation's renewable energy needs. The beneficial use of LFG results in the avoidance of fossil fuel-derived GHG emissions through the displacement with renewable LFGTE, and the avoided biogenic carbon emissions because of sequestration. When this is coupled with the national energy needs, landfills become a major part of the solution to our energy problems here in the U.S.

3.2 INHERENT VALUE OF LFGTE

The production of methane from disposed refuse, if adequately controlled, should be viewed as a positive benefit from landfill disposal. Furthermore, landfills collect and convert methane back to biogenic carbon dioxide (the same biogenic emission that would have been created if the waste were not disposed in the landfill) and can obtain the energy benefit of the methane at the same time. This provides a dual benefit on GHG emissions for LFGTE projects.

Using LFG for energy is a "win/win" opportunity. LFG utilization projects involve citizens, non-profit organizations, local governments, and industry in sustainable community planning and partnerships. These projects go hand-in-hand with community and corporate commitments to cleaner air, renewable energy, economic development, and GHG reductions.

Since the program's inception in 1994, LMOP's efforts have reduced landfill methane emissions by more than 35 million metric tons of carbon dioxide equivalent (MMTCE). The GHG reduction benefits in 2009 alone are equivalent to having planted more than 19.5 million acres of forest, removing the annual emissions from 15.7 million passenger vehicles, or offsetting the use of 199 million tons of barrels of oil consumed (USEPA, 2010).

Figure 3.1 (Themelis, 2009) is based on data provided in the USEPA database of U.S. landfills collecting LFG and shows that 7.8 billion cubic meters of LFG were captured by U.S. landfills in 2006. At an estimated 50% concentration of methane, this amounts to about 3 million tons of methane. If this methane had been allowed to be emitted to the atmosphere, it would be equivalent to 63 million tons of carbon dioxide. Of this, according to Themelis (2008), about 52% of methane captured in the U.S. occurs at landfills with LFGTE. As such, the GHG benefit of LFGTE projects in 2006 was over 32 million tons of carbon dioxide reduced, a value which increases each year as more projects are brought on-line (USEPA, 2010).

SUR Analysis of EPA Database of operating U.S. Landfills

MSW landfilled annually *(1052 landfills)*	MSW landfilled annually in landfills that recover LFG *(376 landfills)*	LFG captured in 2006	Average LFG captured per ton MSW at landfills that recover LFG
189 million tons*	125 million tons	7800 million Nm3	62 Nm3/ton (Nm3: standard cubic meters of LFG)
100%	66%		

*vs 266 million tons landfilled as per BioCycle/Columbia survey[3]

Figure 3.1 U.S. Landfills Collecting LFG (Themelis, 2009)

Producing energy from LFG avoids the need to use non-renewable resources such as coal, oil, or natural gas. This can also avoid gas end-user and power plant emissions of carbon dioxide and criteria pollutants such as sulfur dioxide (which is a major contributor to acid rain), particulate matter (a respiratory health concern), nitrogen oxides (NO_x), and hazardous air pollutants (HAPs). Depending on the technology used to recover energy from LFG and the non-renewable energy that is offset, a LFGTE project can create net reductions in GHG, criteria, and/ or toxic emissions.

Collecting LFG to produce electricity also improves the air quality of the surrounding community by reducing landfill odors and controlling organic pollutants in the LFG, which might not have occurred otherwise. Burning LFG to produce electricity destroys most of the non-methane organic compounds (NMOCs) and odorous compounds that are present at low concentrations in LFG, thereby reducing possible health risks, ozone precursor impacts, and nuisance from these compounds. These benefits can also be created with a simple flaring system; however, generating electricity from existing MSW landfills achieves the same emission reductions but has the added benefit of creating a relatively cost-effective way to provide new renewable energy generation capacity to supply community power needs.

Using power that is produced from these LFGTE (or any other renewable source) ultimately reduces the dependence on foreign fuel and natural gas. This is an added benefit of LFGTE that cannot be directly seen through emissions accounting but is substantial. Besides being renewable, LFGTE is also distributed generation, which allows local communities to provide reliable sources of power that decrease their dependence on energy sources outside of their control and reduces transmission losses because transmission distances are reduced.

LFG projects involve engineers, construction firms, equipment vendors, and utilities or end-users of the power produced. Much of this cost is spent locally for drilling, piping, construction, and operational personnel, and helping communities to realize economic benefits from increased employment and local sales. Businesses are also realizing the cost savings associated with using LFG as a replacement for more expensive fossil fuels, such as natural gas and utility power.

LMOP estimates that there are 530 candidate landfills that have the potential to turn gas into energy, producing enough electricity (approximately 1088 MW) to power more than 692,000 homes, based on 636 homes per gross MW of capacity (USEPA, 2010). This huge potential for LFGTE should not only be recognized but fully supported and incentivized by federal, state, and local legislation, regulation, and policy.

3.3 LFG RECOVERY

Before 1996, LFG recovery and control systems were typically designed and installed based on regulatory enforcement for subsurface LFG migration (i.e., explosive gas concerns under Resource Conservation and Act [RCRA] Subtitle D), odor, groundwater protection, and corrective action, or for financial motivations associated with revenue and tax credits from LFG energy recovery.

The first round of federal tax credits under Section 29 of the U.S. tax code required LFGTE projects to be in service by June 1998 at the latest and allowed credits to be generated through either 2002 or 2007. The USEPA's LMOP was developed in 1994 to promote energy recovery from LFG. An additional LFG tax credit was extended in 2009 under Section 45 of the federal tax code. Various state renewable portfolio standards (RPS) have also incentivized LFGTE development by increasing the price paid by utilities for renewable power. More recently, municipalities have received Energy Efficiency and Conservation Block Grants under the American Recovery and Reinvestment Act of 2009, which they have used to develop LFGTE projects. The successes of these programs are seen in the LMOP statistics detailed above, which give strong support for the continued support of subsidies, tax credits, and other incentives to maximize the number of LFGTE projects.

LFG recovery and control at MSW landfills significantly changed in 1996 with the promulgation of the New Source Performance Standards (NSPS) under 40 Code of Federal Regulations (CFR) Part 60, Subpart WWW, under the Clean Air Act (CAA) that provided a federal level driver for LFG control for the first time. NSPS required the collection and control of LFG as early as December 1998 and continues to regulate the NMOC fraction of LFG as a Clean Air Act pollutant.

After the NSPS took root in 1998 and continued to be phased in over the next decade, air quality compliance became a major driver for LFG projects. The primary emissions of concern were not odor-causing emissions that were primarily sulfur compounds or the control of explosive gas, but rather the NMOCs in their capacity as ozone precursors. NSPS was further strengthened through the promulgation of the landfill National Emission Standards for Hazardous Air Pollutants (NESHAPs) in 2003 under 40 CFR Part 63, Subpart AAAA, which regulated the HAP in LFG. Both regulations require landfills with high NMOC emission rates to collect and control LFG in a manner consistent with the rule to achieve a specific degree of NMOC and HAP reduction.

Conventional LFG control systems have historically focused on the treatment of LFG through filtration or combustion (with a small exception noted for LFG venting systems). Combustion systems typically utilize the methane fraction of LFG as a fuel source, resulting in a reduction in both methane and NMOC emissions. The most common LFG control device is a flare that comes in two broad types: enclosed and candlestick (also referred to as “open” flare). Filtration systems typically utilize a carbon bed to adsorb NMOC compounds onto carbon granules, thereby filtering the volatile organic compounds (VOCs) and HAPs out of the LFG stream, but do not affect the methane.

Energy recovery systems that utilize LFG typically generate electricity using reciprocating internal combustion engines (RICEs) or LFG-fired gas turbines (GTs), or they substitute LFG for other fuels directly in boilers or other combustion systems. RICEs and GTs utilize raw LFG and drive generators that produce electricity. Other types of electricity generating units that are run on LFG include steam turbines and microturbines as well as some experimental fuel cells. In many cases, LFG is used directly as a replacement or supplement for natural gas, occasionally as a direct feed into natural gas pipelines (after removal of carbon dioxide and other impurities), but more often as a medium-BTU gas in industrial boilers or other industrial or commercial combustion devices. LFG has been used on a small scale for vehicle fuel. LFG is now piped as far as 30 miles from a landfill site to an end-user facility.

Directly using LFG in a boiler, dryer, kiln, greenhouse, or other thermal application is occurring in about one-third of the currently operational LFGTE projects. This use of LFG offsets the use of a fossil fuel (e.g., natural gas, coal, and fuel oil) because the user can purchase less utility-provided power or gas. Innovative direct uses include firing pottery and glass blowing kilns; powering and heating greenhouses and an ice rink; and heating water for an aquaculture (fish farming) operation. Current industries using LFG include auto manufacturing, chemical production, food processing, pharmaceutical, cement and brick manufacturing, wastewater treatment, consumer electronics and products, paper and steel production, prisons and hospitals.

Cogeneration (also known as combined heat and power or CHP) projects using LFG generate both electricity and thermal energy usually in the form of steam or hot water. Several cogeneration projects have been installed at industrial operations using both engines and turbines. The efficiency gains of capturing the thermal energy in addition to electricity generation can make these projects very attractive to the communities and customers who they serve.

Production of alternate fuels from LFG is an emerging area. LFG has been successfully delivered to the natural gas pipeline system as both a high-Btu and medium-Btu fuel. LFG has also been converted to vehicle fuel in the form of compressed natural gas (CNG) or liquefied natural gas (LNG), with several projects on-line and additional projects in the planning stages. For example, the Altamont Landfill is the world’s largest and first commercial LFG to LNG facility in the world producing up to 13,000 gallons of LNG per day – enough to fuel 300 waste and recycling collection vehicles. In addition, the Altamont project will reduce carbon dioxide emissions by over 300,000 tons annually (GNA, 2009).

LFG clearly is a very versatile source of energy that can produce base-load or peaking power, a natural gas replacement or supplement, vehicle fuel, or as a raw material for methanol or ethanol production. As noted by Themelis (2008), the U.S. conducts 62.2% of the methane utilization from LFG globally, even though we generate only 23.6% of the landfill methane. Themelis (2008) concludes that "landfills that collect LFG and use it to generate electricity should be placed above those that collect LFG and flare it."

3.4 EMISSIONS FROM LFGTE

Opponents of landfills claim development of LFGTE projects will increase methane emissions at landfills. This purported phenomenon was attributed to an incorrect theory that less LFG will be extracted under the energy recovery scenario in order to maximize methane content. This is simply not true. The two issues (high BTU content of LFG and increased collection efficiency) are not mutually exclusive and can and do co-exist at any landfill. It is not only possible but probable to have a functioning energy recovery plant at a landfill that meets or does better than air quality requirements, and many of the existing landfills with LFGTE plants are doing just that.

Whether the LFG is flared or burned in engines for energy recovery, the landfill is required by federal regulations to achieve the same surface emission limits and LFG system operational requirements in either case. There is no evidence that operation of LFGTE projects affects the ability of the landfill to meet surface emissions requirements of the NSPS or state/local LFG regulations. Any suggestion to the contrary is pure conjecture by parties, who appear never to have owned or operated a landfill, LFG collection system, or LFGTE plant. LFG collection systems at landfills that are required to collect and control LFG for regulatory purposes are not and cannot be operated differently (such as turning off or turning down LFG collection wells) to maximize energy recovery, resulting in increases in emissions.

In fact, once the LFGTE project is installed and operable, the site's flare(s) will remain as backup control device(s) during periods of time when the LFGTE plant is off-line. This provides redundancy in LFG control that will ensure the site can always collect and control LFG. This scenario actually reduces methane emissions by limiting the time when a control device is unavailable and reduces overall LFG system downtime as compared to a flare-only scenario. This also provides additional reductions in NMOC, VOC, and HAP emissions from landfill surface emissions that could occur during system downtime.

LFG-fired energy recovery devices must meet the same organic compound destruction efficiency as flares, per the same federal regulation. Therefore, there are also no expected increases in NMOC/VOC emissions above regulatory thresholds from the combustion device itself when using LFGTE equipment although there is some variation among technologies.

Landfill opponents suggest that LFG engines, which represent the largest majority of LFGTE devices, do not destroy methane as well as flares. Indeed, the capacity of flares to destroy methane is greater than most LFGTE equipment, but the true difference between the two devices is very small with flares and other control devices achieving more than 99% control and lean-burn LFG engines achieving more than 98% control of methane (Solid Waste Industry for Climate Solutions [SWICS], 2007). Reflective of this fact, USEPA, in its mandatory GHG reporting rule under 40 CFR Part 98 allows the use of a default 99% destruction efficiency for methane for all types of LFG combustion devices, including engines.

There are some landfills, which are not required by regulation to collect and control LFG, that are developed for LFGTE. In these cases, **all** of the methane (and other LFG pollutant) emission reductions that occur due to the LFGTE project are voluntary and additional, as these reductions would not have occurred except for recognition and support for LFGTE. These additional LFGTE projects represent a significant reduction in methane emissions that occurs exclusively due to LFGTE projects. Landfill opponents have misquoted this fact as evidence that energy recovery results in lower collection efficiencies, completely ignoring the fact that at some sites, LFGTE is the **sole** driver for the recovery of methane that would not have occurred otherwise.

Interestingly, landfill opponents argue support for voluntary LFGTE projects is misplaced because LFG collection efficiencies are lesser than flares. Certainly some voluntary LFGTE projects collect a limited or fixed amount of LFG (usually because they are only trying to meet a specific energy recovery capacity) but this is only because they are not required to achieve anything more than that. More important, the voluntary projects are just that "voluntary"---without them the methane collection would be zero. Therefore, the significant amount of methane collected under a voluntary program is just that – significant, although it might be possible to collect even greater methane under hypothetical scenarios.

Landfill opponents also claim that promoting LFGTE undercuts composting and other organic diversion projects and can result in increases in emissions. These opponents are particularly critical of a landfill's ability to manage organic wastes without increases in emissions. To that end, Public Sector Consultants (2007) conducted a study of LFGTE projects in Michigan in defense of landfills against a yard waste ban in the state. Public Sector Consultants (2007) concluded that "among sources of waste that have not already been captured, yard waste has the highest organic content and fewest operational challenges to overcome to produce more landfill gas and therefore is an excellent candidate to introduce into landfills to boost energy production. Increasing the amount of organic matter disposed in landfills will increase potential landfill gas production. However, increased gas production coupled with increased collection efficiencies has the potential to negate any increases in emissions associated with the addition of yard waste to the disposal stream at a landfill. Landfill gas collection systems designed to remove the maximum amount of gas possible from the waste are essential to ensure that emissions will not increase as a result of the disposal of additional organic material."

It is clear that even without the counting of the substantial carbon sequestration that occurs in landfills, landfills with LFGTE are a viable and cost-effective option for managing organic wastes. Bogner at al (2007), working for the Intergovernmental Panel on Climate Change (IPCC), summarized work by Delhotal et al. (2006), which found that "…estimated break-even costs for GHG abatement from landfill gas utilization that ranged from about -20 to +70 US$/t$CO_2$-eq, with the lower value for direct use in industrial boilers and the higher value for on-site electrical generation. From the same study, break-even costs (all in US$/t$CO_2$-eq) were approximately 25 for landfill-gas flaring; 240-270 for composting; 40-430 for anaerobic digestion; 360 for MBT and 270 for incineration." These data clearly show the various LFGTE options are much more cost-effective at achieving GHG reductions than composting and other organics diversion strategies. In this time of economic downturn worldwide, it is critical to implement technologies leading to the least costly and greatest savings in reducing GHG emissions.

In conclusion, LFGTE will not result in any increase in methane, organic, and toxic emissions from LFG. In fact, there will likely be an overall decrease due to the redundancy of the control systems, voluntary methane reductions driven by LFGTE projects, and the displacement of fossil fuel use.

3.5 LANDFILL CAPPING

Landfills do not delay final capping without regulatory permission, which can only be granted for legitimate reasons. The development of a LFGTE project is not such a reason. Further, final cover systems can be beneficial to some LFGTE projects by creating a low permeability cover that can reduce air intrusion and increase methane quality. As such, it would not even be in the best interest of a LFGTE project to request a delay in the final cover system. Even if final cover systems are delayed for other allowable reasons, intermediate covers perform in very similar manner to final covers in terms of collection efficiency and methane oxidation. As such, there is no demonstrative effect on collection efficiency when final covers are delayed for any legitimate reason.

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4.0 ORGANICS DIVERSION AND COMPOSTING

4.1 BACKGROUND

Organic wastes (e.g., yard and food wastes) are a potential green energy source as well as a valuable soil amendment. Increasingly, states/provinces are establishing organics diversion goals or mandates to encourage more sustainable waste management practices with multiple environmental goals: producing renewable energy, fuels and compost, saving landfill space, and reducing greenhouse gas (GHG) emissions. Organic waste diversion mandates raise important issues that governmental policy makers need to address, including:

- Diverting organics from highly-regulated landfills deregulates the waste stream. Regulators must ensure that new management of organics will be subject to equivalent environmental, health and safety standards that protect people and the environment.

- The emerging organics recycling industry is anticipating potential revenue from GHG offsets to make these operations more economical and thus build the infrastructure for recycling. However, organics diversion mandates, such as yard waste bans, preclude these facilities from obtaining GHG offset credit for diverting wastes from landfills. This is because regulatory mandates at the state or local level requiring organics diversion will mean that GHG reductions associated with “avoided landfill methane” will no longer be considered “additional,” which is a fundamental prerequisite for earning tradable GHG offsets.

Potential management strategies for organics may include:

- Well-controlled composting to produce valuable soil amendments;

- Reclaimable anaerobic composting (RAC) that produces energy and compost material;

- Anaerobic digestion to produce renewable energy or fuels;

- Gasification of waste to produce fuel or chemicals; and

- Exempting yard waste from landfill bans in states that recognize renewable energy production from landfill gas (LFG)

Some landfill opponents claim it is better environmentally to control landfill methane by keeping organics out of a landfill rather than installing methane control technology at the landfill. Proponents of this position want to have it both ways. They want to discredit landfills as being methane emitters; however when landfills are able to effectively control and reduce methane emissions and recover energy from it, the same proponents of organics waste diversion are reluctant to recognize these reductions because, from a GHG standpoint, it diminishes their arguments in favor of landfill waste diversion.

There are a variety of viable methods to manage waste, and landfills are only one method of disposal. Good design and operation of landfills can go far to address climate change issues and reduce GHG. Landfill disposal and recycling, reuse, composting and waste-to-energy are not mutually exclusive. In fact, major landfill companies and municipalities that own/operate landfills are collectively the largest recyclers of organic wastes in the U.S. However, because they also operate landfills, they seek a balanced and reasonable approach that provides an objective assessment of alternative management strategies to best address climate change.

Control of methane emissions at landfills, or any method that lessens release of GHG or decreases the carbon footprint, should not be opposed because it would result in alternative management methods appearing less attractive. Landfill methane emissions are highly uncertain and cannot easily be measured, but the amount of methane controlled can be directly and accurately measured. Landfill methane control measures reduce GHG emissions at the source. Estimated indirect GHG reductions from avoiding methane emissions at a separate source not under operational control of the party claiming the reductions are speculative. Such indirect emission estimates must be based on site specific conditions to be credible. Indirect calculations often are required to predict the GHG impact of alternatives to landfill disposal.

Direct reduction of landfill methane emissions must be encouraged in addition to support for objective assessments of alternative waste management strategies on a life-cycle basis that further GHG reductions proven to be truly *additional* to the control measures at the landfill.

4.2 LANDFILLING VS. DIVERSION

Some opponents of landfills who also are proponents of organic waste diversion fashion their debate as a battle between landfills and specific diversion strategies. However, the facts are that close to 64% of the U.S. Municipal Solid Waste (MSW) is landfilled, and the waste management industry must identify real world solutions to GHG issues such as controlling methane emissions at landfills, which has been highly successful over the last several decades. The fact that proponents of alternative management methods would argue against continuing these highly effective LFG collection, and also against the only proven alternative--combustion with recovery of electricity--is a greater source of concern. To argue that landfills should not control methane because it may reduce the carbon credits generated by an alternative management strategy is not a credible argument.

This concept of rejecting collection and recovery of LFG because it could negate the benefits of these alternative management strategies is a spurious argument and one discounted as such by experts. Themelis (2009a) states that “the Center for Sustainable Use of Resources (SUR) of Columbia and North Carolina State Universities bases its evaluation and selection of best practices for waste management on sound science, acceptable economics and evidence of practical implementation. Our research work in this area over several years has led us to accept the internationally-proven fact that there are only two ways for managing non-recyclable municipal solid wastes (MSW): By combustion with energy recovery (WTE) or by sanitary landfilling with landfill gas (LFG) recovery.”

“SUR advocates that every possible effort be made to recycle, compost, and combust as much as possible of the MSW generated in the U.S. At the same time, SUR recognizes the dominant role of landfilling and the economic and practical reasons that have resulted in this dominance. We therefore also advocate the use of sanitary landfills and the implementation of measures for maximum possible capture and utilization of landfill gas (LFG) at all landfills."

Reducing methane emissions from landfills lowers the carbon footprint of wastes that have already been put into the landfill. The decision to equip landfills with GHG reduction technology does not impact decisions by generators, cities, schools, hospitals, businesses, etc. as to whether to recycle their wastes or to send the waste to landfills. The landfills do not make waste management decisions – they only accept the wastes that are sent there. Improving landfill methane control systems at landfills will not only reduce methane emission from wastes that have already been disposed in a landfill, but also result in reduced emissions from wastes that are sent there in the future.

Landfill opponents suggest landfill methane control will require already limited capital to be invested in landfills, thereby reducing the availability of capital to be invested in alternative management methods such as composting and anaerobic digestion. In effect, they argue that projects reducing methane emissions from landfills are being funded over less effective methods, and this must be stopped. It is true that capital will flow to those projects that are most cost-effective in achieving a particular objective.

If the objective is to control GHG, capital will flow to those waste management strategies that are most cost effective, such as detailed in Delhotal, et al (2006), that found "…estimated break-even costs for GHG abatement from landfill gas utilization that ranged from -20 to 70 U.S. dollar per metric ton of carbon dioxide equivalent (MTCO2e), with the lower end value for direct use in industrial boilers and the higher value for on-site electrical generation. From the same study, break-even costs were approximately 25 for landfill gas flaring; 240-270 for composting; 40-430 for anaerobic digestion; 360 for mechanical and biological treatment; and 270 from incineration." This research shows that methane controls at landfills, supplemented with energy recovery, are far more cost-effective than other strategies for achieving GHG reductions.

Composting advocates miss the point that improved LFG control systems will add costs to landfill operations. Higher operating costs will result in making alternatives, such as composting and waste-to-energy, *more* financially attractive, not less. The net result of improving LFG control at the landfill will be higher operating costs, resulting in alternatives that are more financially comparable and thus attractive, possibly leading the market to a net diversion of waste away from the landfill due to higher landfill costs.

As Themelis (2009a) noted, "from an environmental prospective, it is incorrect to argue that 'lesser' and widely adopted technologies that reduce greenhouse gas emissions should not be supported so as to make other 'better' technologies appear better."

4.3 REDUCING GHG EMISSIONS BY LFG CAPTURE AND BY DIVERSION OF ORGANICS

Both landfill methane control systems and diversion of organic wastes to alternative waste management strategies, such as composting and anaerobic digestion, can have a beneficial effect on reducing GHG emissions. However, improper or poorly regulated management of organic wastes outside of a highly-regulated, well-constructed landfill can lead to odors, disease vectors (i.e., rodents, birds and insects), water quality problems, health concerns, increased ozone precursor emissions, and increased GHG emissions – just as would be true with poorly regulated landfills.

Bogner, et al. (2007), working for the Intergovernmental Panel on Climate Change (IPCC), stated that "…methane and nitrous oxide can both be formed during composting by poor management and the initiation of semi-aerobic or anaerobic conditions. If states choose to enact strategies to divert organics from management in landfills, those strategies should be accompanied by robust environmental standards. The standards should be designed to ensure that human health and the environment are protected and GHG and other pollutant emissions are not inadvertently increased."

As discussed later in this document, composting operations do in fact result in emissions of not only GHG pollutants but also significant quantities of volatile organic compounds (VOCs), and that these emissions can be measured.

4.4 GHG REDUCTION CREDITS

Organics diversion projects often claim GHG reductions by means of reductions that would be accomplished through avoidance of landfill methane emissions, that is, displacement of landfill methane. Unfortunately, these potential reductions are many times inflated by proponents. Reductions are claimed for avoiding methane that would have been generated in the landfill from the diverted organic waste under uncontrolled conditions. The potential reduction estimates assume that the methane will not be collected and controlled in a landfill with high collection efficiency. The analysis also assumes that no GHG emissions are created from the act of diversion, which would offset the GHG benefit.

Jackel, et al (2005) found that "composting has been proposed as a method to reduce methane emissions from landfills. Nevertheless, compost piles themselves were shown as sources of atmospheric methane." Therefore, the GHG benefit from waste diversion must be carefully analyzed to ensure that it is not providing credits from reductions that are not actually occurring, i.e., are truly additional.

Methane avoidance offset projects, which are proposed to create GHG reduction credits, do not directly reduce landfill methane emissions. The credits that would be generated by these projects are based on assumptions about what methane would have been produced by the landfill had wastes been sent there instead of to the project. Few protocols require verification of avoided emissions at the landfill. Often the landfill had in place or would have been able to install control measures to directly reduce methane emissions – without connection to the "methane avoidance project". This would potentially result in methane reduction double-counting and a discrediting of the value of the credit generated by the methane avoidance project.

The protocols published by Chicago Climate Exchange (CCX, 2009) and currently being considered by the Climate Action Reserve (CAR, 2009b) do not require any verification of what emissions were actually avoided at the landfill nor what direct emissions occur during the act of composting. More directly, the protocols do not require the project developer to identify the landfill(s) at where the diverted waste would have been disposed or to verify the presence and age of the active gas collection system, whether that LFG system is comprehensive or not, or whether the LFG is recovered for beneficial use. All of these conditions would have a direct effect on the net GHG reductions that could be created by a composting project; however, none of them are directly measured (as landfill methane reductions are under the landfill project protocols) under the existing and proposed composting protocols. This puts a substantial cloud over the accuracy of these purported reductions and viability of the GHG credits created.

Instead of requiring direct measurements and the collection of site-specific data, the CCX protocol uses a national assumption to determine the baseline emissions; LFG collection systems are assumed to be commissioned three years after waste is deposited and a default 75% collection efficiency factor is applied to all sites. In other words, the baseline for the CCX protocol assumes 100% release to the atmosphere of potential methane from deposited waste during the first 3 years after waste disposal and 25% release during years 4 through 10. These are assumptions that simply cannot be verified except on a site-specific basis. As such, this practice should be highly scrutinized.

Timing of gas collection installation is very site-specific and driven by many regulatory requirements and business decisions – beyond just the NSPS rule. Sites choose early installation to both prevent and control odor and gas migration as well as to ensure compliance with emission standards. Further, many landfills install gas collection early to support renewable energy projects. Such business decisions have no connection to the so-called "methane avoidance project" and are not under the operational control of the methane avoidance project developer, which is critical in determining the project boundary of the methane avoidance project.

In the CCX protocols and as recommended in the draft CAR protocol, no direct emissions measurement occurs at composting operations to verify project emissions. Projects are only required to estimate baseline emissions using a LFG model with default assumptions for the avoided methane and then quantification of project emissions by monitoring temperature to determine pathogen reduction. This is a health-based performance standard, not an emissions quantification method, and provides no real data relative to the amount of direct emissions.

The CCX protocol also states that "composting, when managed properly, does not generate significant methane or nitrous oxide emissions. Therefore, methane and nitrous oxide emissions are not included in the GHG accounting boundary since only projects that are properly managed, as demonstrated by compliance with applicable regulations [USEPA health based standard for pathogen destruction] and compost permit requirements, are eligible to earn offsets." This flies in the face of direct evidence that these emissions do indeed occur and thus should be directly measured. As discussed later in this document, composting operations do in fact result in emissions of not only GHG pollutants but also significant quantities of volatile organic compounds (VOCs), and that these emissions can be measured.

Based on their recent report (CAR, 2009b), CAR appears to be recommending the adoption of the majority of the criteria for methane avoidance project accounting from the CCX protocol. CAR likes to suggest that their protocols represent the "gold standard" in the GHG credit market since the protocols are very stringent and provide a high level of certainty that the reductions are additional and real. However, we see none of this high level of certainty in the CCX protocol or the proposed CAR protocol.

CAR suggests that testing of direct compost emissions should not be required since it is cost-prohibitive; however, since there is such limited data on these types of measurements, there are no credible emission factors that could be used in lieu of testing data. As such, site-specific testing of composting emissions must be a component of any methane avoidance project protocol. CAR also suggests that proper management of composting operations will avoid all of the emission and odor related issues for composting - *without any direct evidence or evaluation on a project-specific basis*. Due to the high potential for poor management and anaerobic conditions, passive open windrow composting operations should be excluded from consideration under these protocols because these practices are not beyond business as usual when it comes to proper compost management to reduce GHG emissions.

The CAR report is full of other assumptions that must be verified on a site-specific basis before they can be demonstrated to be true, such as their statements that: (1) hauling distances for composting will be equal to or shorter than landfills; (2) methane generated during composting will be oxidized in the compost pile and not emitted, and (3) VOC emissions from composting are less than if the wastes are managed in other ways, such as landfilling. Each of these statements must be verified on a project-specific basis in order to determine the net impact to the project.

In summary, a comprehensive review and complete re-work is necessary for the existing compost project protocols to ensure that the management practices reflect beyond business as usual criteria, the direct emissions are measured at the source, and the avoided methane emissions are determined on a project-specific basis, including specifics related to the landfill(s) where the organic waste would have been disposed. Only then will these protocols result in GHG reductions that are real, additional, and accurate and GHG credits that have a high degree of certainty and meet the "gold standard" for tradable credits.

Landfills, on the other hand, which want to claim GHG credits for methane reductions must demonstrate that their reductions are truly additional. That is, they are beyond any regulatory requirements or what would be considered "business as usual" (CAR, 2009a). Further, landfills are only given credits for the methane reductions directly measured. Organics diversion projects should be held to the same standard. The U.S. has an active carbon credit trading market with landfill methane reduction projects representing the largest percentage of projects with verified carbon credits (CAR, 2010). These credits often command high value on the market, and result from a recognition by the carbon market that these reductions are truly additional. All methane avoidance projects should be held to the same criterion of additionality and the same robust verification and measurement requirements to ensure the legitimacy and value of the GHG offsets system.

4.5 LIFE CYCLE ASSESSMENTS (LCA)

Life-cycle assessment (LCA) can be used to better understand the greenhouse gas benefits of various technologies and waste management methods. LCA analyses have been performed comparing landfills to composting or other organic diversion options. Barlaz, et al (2003) found that "…diverting more organics from a bioreactor landfill to composting decreases the amount of greenhouse gas emissions saved…" The City of Des Moines, Iowa funded a LCA study of GHG emission balances of yard waste composting versus landfilling (Sebesta Blomberg, 2008). The Des Moines study found that "although composting enjoys a reputation as being more environmentally beneficial than landfilling, the collection of landfill gas and generation of electricity from those renewable gases leads to more than three times the amount of greenhouse gas reductions than does the composting operation."

LCA studies (USEPA, 2006 and various studies cited therein) are designed to best understand the true impact of a technology or method of operation. They quantify methane reductions or avoidances and are critical of indirect benefits that cannot be measured. LCAs consider all aspects of a proposed strategy for managing organic wastes, including transportation, energy, direct, and indirect emissions and reductions as well as calculate the cost-effectiveness of each option for its ability to reduce GHG emissions. If such LCA studies are done in a reasonable and balanced manner, the resulting conclusions reveal that every specific case studied leads to different climate change benefits for different options.

As another example, a recent and very detailed LCA study by the Earth Engineering Center (R.van Haaren, M.S. Thesis, Columbia University, included in Themelis, 2009b) showed that the use of yard wastes as Alternative Daily Cover (ADC) is environmentally superior to windrow composting of these wastes, mainly because it avoided digging up and transporting soil, as required by USEPA regulation for daily cover. Such a use of yard wastes is practiced widely in California where 2.1 million tons of source-separated yard wastes are used as ADC in landfills.

Hyder Consulting Pty Ltd (Hyder, 2010) conducted a comparative GHG LCA of the Wollert Landfill in Australia. This study included an analysis of five scenarios, which were modeled and compared as to their GHG impacts/benefits. All scenarios included enclosed and controlled composting of green wastes and landfilling of residential from waste processing. The base case included landfilling of all other organic wastes, MSW, and commercial/industrial waste. Scenario No. 1 included aerobic mechanical and biological treatment (MBT) of food wastes, household garbage, and commercial and industrial garbage. Scenario No. 2 included anaerobic MBT of food wastes, household garbage, and commercial and industrial garbage. Scenario No. 3 included enclosed composting of all organics and landfilling of all other wastes.

Despite pre-conceived notations that the landfill scenario (base case) would perform poorly, the Hyder study (2010) concluded that "…across the range of assumed recovery rate values, the greenhouse gas benefits of energy recovery and carbon storage exceeded the costs of methane emissions… Best practice landfill with good performance management is a potentially sound option from a greenhouse gas management perspective…Anaerobic MBT appears to be a better greenhouse option than aerobic MBT. This suggests that from a greenhouse gas perspective it is better to focus on maximizing energy recovery from biological material rather than to generate stabilized organic products…Diversion of food organics to the compost stream has a similar performance (but usually slightly worse) to disposal at Wollert landfill, from a greenhouse gas perspective… When emphasis is given to greenhouse gas pollution over centuries, landfill performance is better than that of MBT facilities or enclosed composting with food separation." Therefore, even when compared to controlled composting operations (as opposed to open windrow composting), landfilling of food wastes was demonstrated to have greater GHG reduction benefit.

4.6 COST-EFFECTIVENESS ANALYSIS

Cost effective measures are an important consideration in determining support for GHG reduction methods. Themelis (2009a) stated that "sustainable waste management requires critical analysis of the science and technology behind policy decisions, in order to select the most environmentally beneficial solutions. Policy decisions must also be based on practicality and economics or the perceived solutions risk failure of implementation due to physical barriers or high costs."

Bogner et al (2007) reported on the cost-effectiveness for different waste management strategies for reducing GHG emissions. The report was based on a study by Delhotal et al (2006), which found that "…estimated break-even costs for GHG abatement from landfill gas utilization that ranged from -20 to 70 U.S. dollar per metric ton of carbon dioxide equivalent, with the lower end value for direct use in industrial boilers and the higher value for on-site electrical generation. From the same study, break-even costs were approximately 25 for landfill gas flaring; 240-270 for composting; 40-430 for anaerobic digestion; 360 for mechanical and biological treatment; and 270 from incineration." Methane controls at landfills, supplemented with energy recovery, were far more cost-effective than other strategies for achieving GHG reductions.

4.7 CARBON SEQUESTRATION

Composting proponents have claimed an advantage over landfills for carbon sequestration that occurs in the soils where the compost is applied. However, soil cannot permanently sequester the carbon. As Favoino and Hogg (2008) concluded, in a paper largely in support of composting, "composting can only store carbon temporarily in soils. The carbon will be released, in the long run, into the atmosphere."

Interestingly, the same supporters of carbon sequestration credit for composting do not recognize carbon sequestration that occurs in landfills. Since 1998, the amount of carbon sequestered each year in landfills can offset the net methane emissions from landfills as detailed by the U.S. Environmental Protection Agency (USEPA, 2006) and Weitz, et al. (2002). Weitz et al. indicated that "when the consideration of carbon storage is included in the calculations, it dramatically offsets all of the energy and landfill emissions. " USEPA has drawn similar conclusions (USEPA, 2006; 2009a).

Freed et al (2007) states that "the effect of this process [carbon sequestration] on overall U.S. greenhouse gas emissions is quite significant. In comparison to other sources and sinks in the U.S. greenhouse gas inventory, the annual increases in storage of carbon in landfills in 2005 offset 51 percent of the landfill methane emissions [and] exceeded, in absolute magnitude, the emissions from 47 of the 54 source categories." As the amount of waste disposed in landfills continues to increase, the magnitude of carbon sequestration also increases.

Bogner, et al. (2007), working for IPCC, stated that “since lignin is recalcitrant and cellulosic fractions decompose slowly, a minimum of 50% of the organic carbon landfilled is not typically converted to biogas carbon but remains in the landfill. Carbon storage makes landfilling a more competitive alternative from a climate change perspective, especially where landfill gas recovery is combined with energy use.”

Clearly, as stated by Barlaz (1998), “carbon sequestration is one factor that should be considered in comparing the environmental benefits and liabilities associated with landfills in specific and municipal solid waste management strategies in general.” And when that is done, landfill carbon sequestration can be seen as a benefit in preventing carbon from re-entering the global carbon cycle.

4.8 NATIONAL ABILITY TO MANAGE ORGANICS DIVERSION

Landfill opponents have advocated complete diversion of organics from landfills as a means to achieve methane reductions, particularly diversion and composting of the food waste fraction. The principal fault in this reasoning, as stated by Themelis (2009a) “…is the inherent assumption that, given the ‘correct’ government law or policy, it will be possible to compost rather than landfill the 30 million tons of U.S. food wastes that are mixed in the U.S. MSW annually. Studies undertaken by SUR in 2008-2009 clearly show the reasons that limit composting of food wastes.”

“One of our studies revealed that in order to compost both yard and food wastes, it is necessary to source-separate and collect each portion separately; food wastes decompose rapidly and their collection is more problematic. In North America, there have been only two large scale collections of food wastes, both in Ontario, Canada: Food wastes are collected separately and processed in anaerobic digestion systems that, on a per ton basis, are as capital intensive as waste-to-energy plants. Of these two facilities, one (Dufferin, 25,000 tons/year) has been successful while the other (Newmarket, 120,000 tons/year) has been plagued by odor problems.”

“A second study concluded that food wastes cannot be composted aerobically with yard wastes in open air windrows, which is the principal means of composting in the U.S., because of undesirable odors. Our study has shown that the only methods available to compost food wastes aerobically are, either in aerated fabric-covered piles (e.g., the Gore-Tex system) or in in-situ vessels. Both of these systems require a much higher capital investment than the windrow system.”

4.9 ORGANIC WASTES AS BIOCOVERS

Methane oxidation occurs in various types of landfill covers, including simple soil covers, and converts a portion of the anthropogenic methane back into biogenic carbon dioxide. Biocovers, using various types of organic wastes and materials, perform even better as oxidizers of methane than soil. Biocovers offer a viable option for managing organic wastes in landfills, including initial use as biocovers to reduce methane emissions in newly disposed waste and ultimate production of methane, which can be collected and beneficially used as renewable energy, once the organic cover material is incorporated into the refuse mass.

The research on methane oxidation, as summarized by SWICS (2009) and Chanton, et al (2009), demonstrate that daily cover soils oxidize methane to a greater degree than many low permeability final cover soils. Chanton et al (2009) reports values ranging to 55% for certain types of daily cover soils. Spokas et al (2009), Abichou (2006), and Barlaz et al (2004) have found similar values. Bogner et al (1997) has gone as far as to suggest that "the high observed rates of methane oxidation also argue against geomembrane covers for control of gaseous emissions…"

Biocovers used as alternative daily cover (ADC) have been reported by Abichou (2004), Barlaz et al (2004), Chanton et al (2009), and others to have even greater methane oxidation potential than soil covers (above 55%), thus creating an excellent use in methane reductions for the same organic materials that the landfill opponents claim will cause excess methane to be released. This serves as an additional control measure for any methane not controlled in the active disposal areas by the gas collection system. Barlaz et al (2004) reported that "biocovers can reduce landfill gas emissions in the absence of a gas collection system and can serve as a polishing step in the presence of an active system"

Bogner et al (2007), working for IPCC, has stated that "for many countries which continue to rely on landfilling, increased utilization of landfill methane can provide a cost effective mitigation strategy. The combination of gas utilization for energy with biocover landfill cover designs to increase oxidation can largely mitigate site-specific methane emissions. These technologies are simple and can readily be deployed at any site."

The most common biocover in use at landfills is shredded yard waste as ADC. Landfill opponents suggest that this activity should be discontinued as it creates additional methane emissions. As noted above, such a position discounts the methane oxidation value for the biocover. It also discounts other life-cycle benefits for the use of green waste ADC as detailed below.

The Los Angeles County Sanitation Districts (LACSD, 2008), who owns/operates both landfills and composting facilities, completed a comprehensive study comparing the use of yard waste as ADC versus composting of the same waste. The study included two models and a literature review using a third model. The models included USEPA's Waste Reduction Model (WARM), which is a general purpose tool useful for analyzing a variety of solid waste management practices including yard waste composting and landfilling; the Canadian EPIC model applied to yard trimmings composting and landfilling; and LACSD's own analysis. LACSD's study concluded that "all three life-cycle models show ADC (or the similar landfilling scenario) to reduce GHG emissions substantially more than green waste composting." Themelis (2009b), in a SUR project, reported that "…according to the LCA, windrow composting method has higher adverse effects than use of green wastes as ADC."

LACSD further concluded that "although green waste ADC provides substantially better GHG reductions than composting, composting is an important waste diversion strategy that complements, rather than replaces, ADC use. This study highlights the importance of case-specific life-cycle analyses when assessing relative GHG emissions of organics management techniques."

4.10 POTENTIAL IMPACTS FROM COMPOSTING

There is a variety of potential air quality and GHG impacts from composting or other organic waste diversion strategies. Transportation activities, direct source emissions, and energy use present the primary impacts that would be expected from these waste management strategies. An analysis of composting should consider increased transportation impacts, which can include GHG and other emissions, that occur from additional mobile source trips to collect and manage the organic waste and bring the finished product to market. All organic diversion strategies involve some form of energy input, which also creates GHG and other emissions from electricity or fossil fuel production and subsequent use. Since composting itself does not create energy, impacts from composting can include loss of renewable energy value from the recovery of methane at the landfill, which would have beneficially used the LFG.

Organic waste diversion operations also have direct emissions of various pollutants, including GHG. For example, Jackel, et al (2005) found that although "composting has been proposed as a method to reduce methane emissions from landfills. Nevertheless, compost piles themselves were shown as sources of atmospheric methane." Also, the phenomenon of volatile organic compound (VOC) emissions from composting was first studied by the South Coast Air Quality Management District (SCAQMD) in support of their rule (Rule 1133) to require control of composting emissions. The SCAQMD conducted three studies (SCAQMD, 1996a, 1996b, and 2001) and found methane emissions from all three sites they studied, indicating that methane emission from composting is not an isolated issue. The highest of these tests (SCAQMD, 1996a) showed that annual average methane emissions would be more than 144,000 MTCO2e from a co-composting operation. These tests included passive, open windrow green waste and co-composting operations.

Bogner, et al. (2007), working for the IPCC, stated that "…methane and nitrous oxide can both be formed during composting by poor management and the initiation of semi-aerobic or anaerobic conditions." Boldrin et al (2009) reported that "…the release of nitrous oxide from the compost as it is being used is not well documented and, similarly, the avoided emissions not well quantified: some authors suggest a net savings of nitrous oxide when using compost instead of mineral fertilizers, some others report loads to the environment."

Andersen, et al (2010) found through their field testing of windrow composting of garden waste that "…compost windrow facilities may contribute with significant emissions of GHGs (especially CH4 and N20) to these atmosphere." On the numeric basis, Andersen, et al (2010) found that the emissions of methane and nitrous oxide could range from 1.9 to 2.9 kg methane per Mg and 0.03 to 0.08 kg nitrous oxide per Mg of garden waste. That equates to 79.8 to 121.8 lb CO2E per ton for the projected combined methane and nitrous oxide emissions from composting.

The SCAQMD studies were some of the first to quantify the VOC (a ground-level ozone precursor) and ammonia (an odorous compound and precursor to fine particulate matter) emissions from composting. The SCAQMD concluded "depending on the throughput, the largest green waste facility [in the SCAQMD] is estimated to emit up to 600 tons per year of VOC, which would be considered among the top five VOC emitters in the SCAB [South Coast

Air Basin]."   Further, open windrow composting represents by far the greatest percentage of existing composting facilities in the U.S.

Card and Schmidt (2008a), under contract to the San Joaquin Valley Air Pollution Control District (SJVAPCD), which is considering regulating composting emissions similar to the SCAQMD, summarized available emissions data on composting operations. Their analyses suggested that the average VOC emission from green waste composting is approximately 9.85 lb/ton of compost feedstock. This results in uncontrolled VOC emissions of more than 360 tons per year (tpy) of VOCs for a moderately-sized, 250-ton per day (tpd) facility, which would be considered a major source under all federal, state, and local attainment and non-attainment air quality permitting programs.

According to Card and Schmidt (2006, 2008b, 2008c), when food waste is added, these emissions can increase to as much as 38.5 lb/ton, which would equate to over 1,400 tpy of VOCs emissions for that same 250-tpd facility. The same facility where these food waste composting emissions were studied has also had major odor problems as documented by Card and Schmidt (2006), including enforcement action from the local air district due to odor complaints.

Best management practices (BMPs) and regulatory performance standards are needed for all waste management options to ensure that they do not have negative impacts on climate change and ambient air quality. In the case of composting, BMPs to maintain an aerobic state and reduce methane emissions, and direct collection and control of compost emissions to reduce VOCs, are needed. Again, no waste management technologies can simply be assumed to create air quality and GHG benefit just because they seem "green," and the documented/quantified VOC emissions from composting provide us with a cautionary tale from which this lesson should be learned.

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5.0 BIOREACTOR LANDFILLS

5.1 BACKGROUND

The current state of the practice for municipal solid waste (MSW) landfill design, construction, regulatory compliance, and energy recovery are all centered around the concept that MSW will be deposited in conventional “dry tomb” landfills, where the overriding goal is to prevent moisture infiltration. Using life-cycle assessment (LCA), bioreactor landfills have a substantial greenhouse gas (GHG) and renewable energy benefit through the enhancement of landfill gas (LFG) to energy (LFGTE) potential relative to conventional landfills, as detailed below.

A bioreactor landfill, as the term is being used in the landfill industry, is an MSW landfill that utilizes enhanced microbial processes under controlled anaerobic conditions to accelerate the decomposition of refuse. In the solid waste industry, bioreactor landfills are considered an alternative to the “conventional” MSW landfill. A bioreactor landfill takes a different approach to liquids management. Instead of limiting liquids addition into the refuse mass, a bioreactor landfill requires the addition of supplemental liquids to achieve optimum moisture content, i.e., greater than 40 percent moisture by weight or so-called “field capacity.”

Major obstacles to the implementation of bioreactor landfills include misinformed perceptions that bioreactor landfills will cause additional environmental harm, regulations that do not fit with the bioreactor model, and permitting obstacles and time delays that increase costs and unreasonably limit the bioreactor potential.

5.2 REGULATORY REQUIREMENTS

Prior to the passage of the Solid Waste Disposal Act of 1965 (SWDA), which was the first federal regulation addressing solid waste management, MSW landfills were open dumps with limited environmental and operational controls. Landfills were constructed without liners, leachate collection systems, LFG controls, groundwater and surface water monitoring, and operational controls. The net result was significant negative environmental impact to the groundwater and surface water resources, as well as safety concerns resulting from LFG migration. The SWDA began the process of change by establishing the U.S. Environmental Protection Agency’s (USEPA’s) Office of Solid Waste and led to the development of our current solid waste management rules at the federal and state levels.

By the mid-1970s, all states had adopted solid waste management regulations, but the regulations varied from state to state. Some states established permitting programs and set minimum design and operational standards. Open burning was banned and the concept of the modern sanitary landfill was beginning to be implemented, albeit on a very rudimentary basis.

The Resource Conservation and Recovery Act (RCRA) was promulgated in 1976 and dramatically expanded the federal government’s role in managing waste disposal. RCRA required the USEPA to develop design and operational standards for sanitary landfills (i.e., commonly referred to as Subtitle D MSW landfills) and close or upgrade existing open dumps that did not meet specific standards. In 1979, the USEPA developed criteria for sanitary landfills that included siting restrictions, endangered species protection, surface water protection, groundwater protection, disease vector control, open burning prohibitions, explosive gas control, fire prevention using daily cover, and prevention of bird hazards to aircraft. RCRA was further amended in 1984 and 1991.

The 1984 amendments required the USEPA to assess and, if appropriate, revise the sanitary landfill requirements. The 1991 amendments established new federal standards for MSW landfills addressing revised locational and operational standards and added design standards, groundwater monitoring requirements, corrective action requirements for known environmental releases, closure and post-closure care requirements, and financial assurance requirements to demonstrate the ability to pay for long-term care of the landfill (NSWMA, 2007).

Under RCRA Subtitle D, all MSW landfills must be constructed with a prescriptive lining system (or demonstrated equivalent), including a leachate collection and removal system (LCRS). Landfill cover systems under Subtitle D were also prescribed to achieve a greater degree of environmental protection. This created the concept of a “dry tomb” landfill that was designed to minimize the introduction of liquids into the landfill through infiltration of precipitation and to collect and remove any liquids that did pass through to become leachate. The philosophy behind this landfill design concept was to reduce the potential for leachate generation and subsequent potential release to groundwater or surface water resources.

Subtitle D has generally been successful in minimizing the formation of leachate and controlling its release into the environment. However, the regulation has met with limited success in the optimum management of LFG. The dry entombment of a landfill does not eliminate LFG generation; rather it just slows the rate of microbial degradation so that LFG is produced over a longer period of time.

In March 2004, the USEPA revised the criteria for MSW landfills to allow states to issue research, development, and demonstration (RD&D) permits and assumed that the states would adopt the rule and receive approval of their respective rule changes from the USEPA. The USEPA proposed this alternative with the sole purpose of advancing innovative solid waste technologies. The RD&D permits allow variance from some parts of the criteria under RCRA Subtitle D (40 Code of Federal Regulations [CFR] Part 258). However, owners and operators must demonstrate that the operations permitted under RD&D will not result in an increased risk to human health and the environment.

Examples of variance granted by the RD&D permit are exemptions from precipitation run-on, liquids restrictions, and final cover criteria set forth in §258.26(a)(1), §258.28(a), and Subpart F, respectively. This allows individual states the right to grant permits to test and employ bioreactor landfills and related technologies. The permit is issued initially for three-years, with up to three three-year renewals.

5.3 LFG GENERATION FROM BIOREACTOR LANDFILLS

The organic fraction of MSW placed into a landfill begins to degrade and produce LFG through biochemical reactions. These organic compounds are initially oxidized. However, as the oxygen levels decrease, the principal bioreactions become anaerobic. Anaerobic decomposition takes place in three stages; the last of which is where methane (CH_4) is consumed by methanogenic bacteria. These methanogenic microbes thrive in a high moisture, low oxygen environment. The resulting gas is commonly referred to as LFG and typically is comprised of:

- CH_4 (45 - 60 % by volume);
- Carbon dioxide (CO_2) (40 - 60 % by volume); and
- Non-methane organic compounds (NMOCs) (100-3000 parts per million by volume (ppmv) as hexane)

For a given amount of waste disposed at a landfill, decomposition peaks quickly (as soon as oxygen is depleted and methanogens mature), possibly in months, but then begins a steady decline. This decline is proportional to the amount of waste left (referred to as "first order kinetics"). Complete decomposition may require decades, depending on conditions at the site.

The decline of decomposition of waste, however, is relatively slow compared to the increase in gas production because of more and more waste being received at the site. The net total production of LFG over time is illustrated in Figure 5.1. For a conventional landfill, the LFG generation rate (typically measured in standard cubic feet per minute [scfm]) increases steadily but slowly during the active life of the landfill (i.e., as refuse continues to be received). LFG generation reaches its peak approximately a year after closure, after which time the generation rate declines, first more rapidly and later more slowly over an extended period of time. This long "tail" of LFG production is particularly symptomatic of the "dry tomb" landfill where MSW degradation has been impeded through lack of moisture, resulting in a large percentage of LFG generation occurring many years after closure. This prolongs the post-closure care period for landfills and reduces the viability of energy recovery.

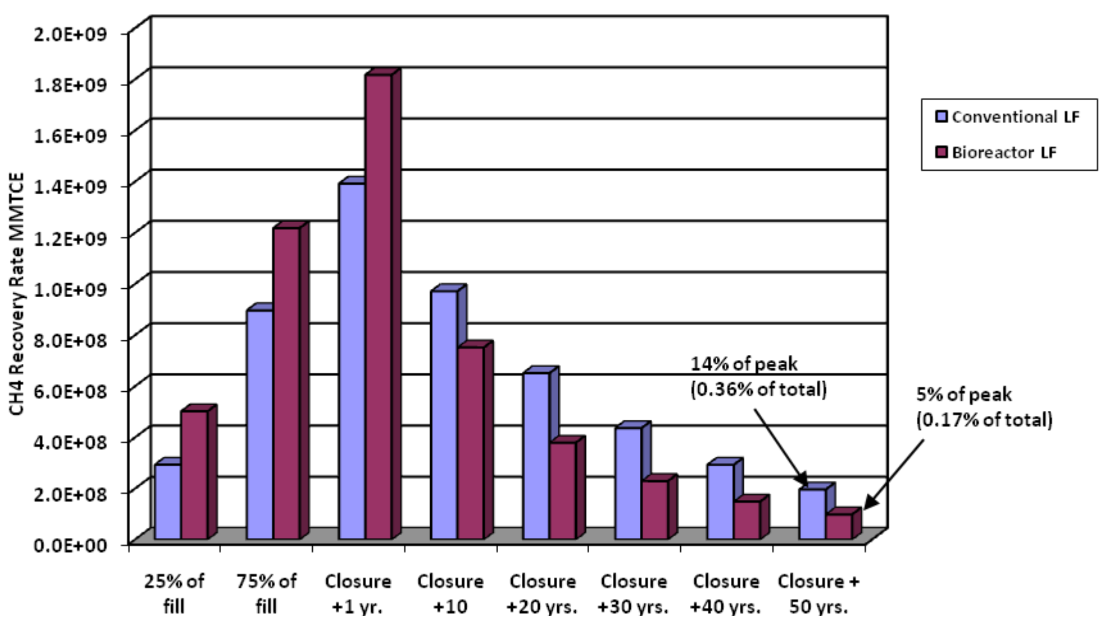

Figure 5-1. Methane Recovery Rates, Conventional vs. Bioreactor

For a bioreactor landfill, conditions more favorable for sustained anaerobic decomposition are maintained from the beginning (via liquid recirculation and addition). Decomposition reaches a higher peak and then declines more rapidly as also illustrated in Figure 5-1.

5.4 COMPARISON OF BIOREACTOR AND CONVENTIONAL LANDFILLS

Bioreactor landfill research and development is gaining increasing prominence in the landfill industry in the U.S. The waste industry is considering the potential benefits that are offered by a bioreactor landfill through various research and full-scale demonstration projects. Benefits of a bioreactor landfill include increased disposal capacity (i.e., more waste can be placed within a fixed volume of landfill air space), shorter post-closure maintenance periods for LFG and leachate management, and better profiles for energy recovery from LFG. If all of these benefits were to come to fruition, the bioreactor landfill could transform the landfill industry by significantly reducing the long-term costs to operate a landfill site and increase the financial viability of both public and private landfill operations.

A bioreactor landfill, as discussed here, is an MSW landfill that utilizes enhanced microbial processes under controlled anaerobic conditions to accelerate the degradation of refuse. The Solid Waste Association of North America (SWANA) has defined a bioreactor landfill as "any permitted Subtitle D landfill or landfill cell where liquid…is injected in a controlled fashion into the waste mass in order to accelerate or enhance biostabilization of the waste." This enhanced degradation can more rapidly stabilize the refuse mass and leachate quality and accelerate LFG generation. This stabilization is accomplished through the control of moisture, temperature, pH, nutrients, and other properties within the refuse mass.

5.5 GENERAL DIFFERENCES BETWEEN A BIOREACTOR AND TRADITIONAL LANDFILL

A bioreactor landfill is specifically designed and operated to ensure that enhanced microbial processes can occur. Instead of limiting liquids, liquids are added into the refuse mass via both recirculation of collected leachate and the addition of supplemental liquids to achieve optimum moisture content (i.e., greater than 40 percent moisture by weight).

Specifically, the LFG and leachate control systems are expanded to account for the increased gas and leachate production. Liquids addition was strictly prohibited under 40 CFR, Part 258; however, the promulgation of the RD&D requirements in March 2004 provided flexibility to landfill operators to add these liquids to landfills in accordance with permit, design, operational, and performance requirements.

Subtitle D has been successful in minimizing the formation of landfill leachate and controlling its release to the environment through the implementation of cover management practices, prescriptive bottom liner and final cover system design requirements, and storm water controls. However, the regulation only addressed LFG control in the context of the explosive hazards presented through offsite migration. The "dry tomb" design philosophy espoused under Subtitle D does not eliminate LFG generation; rather it just slows the rate of microbial degradation so that LFG is produced over a longer period of time. This phenomenon has substantially lengthened the post-closure care period for the operation of LFG collection and control systems. In addition, the "dry tomb" approach to landfill design and operation has constrained the optimum utilization of LFG for energy recovery.

With the enhanced microbial activity in a bioreactor landfill, LFG generation and recovery rates have been demonstrated to increase substantially over the short-term because of the accelerated and more complete degradation of the biodegradable components of the refuse mass. As described below, the gas collection and control system (GCCS) can be enhanced and gas utilization technologies employed to effectively manage the potential challenges of accelerated and increased LFG production. LFG generation (and subsequent recovery) at a bioreactor landfill is anticipated to be limited to a shorter time horizon after landfill closure, thereby significantly limiting the post-closure period for LFG control (refer to Figure 5-1) and reducing the life-cycle methane emissions because more of the gas generation occurs when the landfill is required to have comprehensive controls.

Also, the methane recovery potential at a bioreactor landfill creates a more financially viable situation because LFG generation occurs at higher levels over a shorter time period, thus allowing for more methane recovery with less operational cost (i.e., fewer years of operation) for an LFGTE facility. These shorter time periods of LFG generation are also more consistent with the typical life spans of LFGTE equipment, thereby reducing capital and replacement costs.

5.6 WASTE STABILIZATION

Additional benefits of bioreactor landfills are the accelerated stabilization and settlement of the refuse mass, resulting in increased air space capacity within the same landfill footprint. This allows for more waste to be placed into the same air space, providing for more efficient utilization of the landfill footprint, which should help alleviate any landfill capacity shortage as well as allow additional revenue to be generated from the same landfill footprint. For conventional, non-bioreactor landfills, the current “dry tomb” landfills, the recovery of air space occurs too slowly to be of any practical use to the landfill operator during the active life of the landfill.

There is also the potential for more rapid redevelopment of the landfill after closure (end use implementation) because of better settlement scenarios. Longer-term landfill settlement will continue to occur at a conventional dry-type landfill well into the post-closure period, which can delay redevelopment and potentially limit the available redevelopment options.

5.7 COVER

One of the key design and operational requirements of a sanitary landfill is the placement of daily, intermediate, and final cover systems. Landfill cover practices have a significant effect on the amount of precipitation that infiltrates into the refuse mass, thereby reducing the moisture content of the landfill and LFG and leachate generation. In addition, the design of intermediate and final cover systems plays a role in the control and treatment of LFG emissions.

The primary function of the final cover system (and sometimes the intermediate cover system) is to limit the infiltration of precipitation into the refuse mass and provide a suitable foundation for the establishment of final cover vegetation. Final covers typically consist of the following major components (from the top down):

- **Vegetative layer:** Soil layer with suitable chemical and physical characteristics to support the final cover vegetation and minimize erosion.

- **Protective layer:** Soil layer that protects the barrier layer from weather and other environmental factors and allows roots from the vegetation layer to grow without damaging the barrier layer.

- **Drainage layer:** Porous soil (e.g., sand or gravel), geocomposite, or combination soil/geocomposite drainage layer that provides controlled drainage of moisture above the barrier layer and release of soil pore pressure in the final cover system.

- **Barrier layer:** Composite low permeability soil and geomembrane layer that limits the infiltration of water into the refuse mass.

- **Grading layer:** Soil layer that provides appropriate slope and suitable foundation for construction of the barrier layer.

The goal of a conventional landfill is to minimize the introduction of liquids into the refuse mass, while the goal of the bioreactor landfill is the opposite. Bioreactor landfill operations seek to use naturally occurring precipitation, collected surface water runoff, liquid wastes, collected leachate, and other sources of moisture to increase the moisture content of the landfill to facilitate the bioreactor process.

This necessitates a different strategy for cover design and installation. Bioreactor landfills utilize more porous covers so as not to inhibit infiltration and recirculation of liquids. In many cases, these layers are biologically active (e.g., compost or shredded green waste) so that the cover can assist in the attenuation and oxidation of CH_4 and NMOCs despite being of greater permeability.

Methane oxidation occurs in various types of landfill covers, including simple soil covers, and converts a portion of the anthropogenic methane back into biogenic carbon dioxide. It has also been shown that biocovers, using various types of organic wastes and materials, perform even better as oxidizers of methane than soil. This fact provides a viable option for managing organic wastes in landfills, including initial use as biocovers to reduce methane emissions in newly disposed waste and ultimate production of methane, which can be collected and beneficially used as renewable energy, once the organic cover material is incorporated into the refuse mass. For bioreactor landfills, biocovers can also be used for intermediate and final cover systems.

The research on methane oxidation, as summarized by SWICS (2009) and Chanton, et al (2009), demonstrate that daily cover soils oxidize methane to a greater degree than many low permeability final cover soils. Chanton et al (2009) reports values ranging to 55% for certain types of daily cover soils. Spokas et al (2009), Abichou (2006), and Barlaz et al (2004) have found similar values. Bogner et al (1997) has gone as far as to suggest that “the high observed rates of methane oxidation also argue against geomembrane covers for control of gaseous emissions…”

Biocovers used as alternative daily cover (ADC) have been reported by Abichou (2004), Barlaz et al (2004), Chanton et al (2009), and others to have even greater methane oxidation potential than soil covers, thus creating an excellent use in methane reductions for the same organic materials that the landfill opponents claim will cause excess methane to be released. This serves as an additional control measure for any methane not controlled in the active disposal areas by the gas collection system. Barlaz et al (2004) reported that "biocovers can reduce landfill gas emissions in the absence of a gas collection system and can serve as a polishing step in the presence of an active system"

Bogner et al (2007), working for Intergovernmental Panel on Climate Change (IPCC), has stated that "for many countries which continue to rely on landfilling, increased utilization of landfill methane can provide a cost effective mitigation strategy. The combination of gas utilization for energy with biocover landfill cover designs to increase oxidation can largely mitigate site-specific methane emissions. These technologies are simple and can readily be deployed at any site."

Bioreactor covers can also support a variety of plant life since the fear of damaging an underlying impermeable membrane is not a concern. Furthermore, bioreactor landfills typically include engineered systems beneath cover systems to evenly distribute leachate and other liquids throughout the landfill. This even distribution of moisture allows for uniform settling of the landfill as the organic matter evenly degrades and the majority of this settlement takes place during its operating life.

5.8 LIFE-CYCLE COMPARISON OF GHG EMISSIONS FROM BIOREACTORS, TRADITIONAL LANDFILLS AND COMPOSTING

Researchers at North Carolina State University conducted a LCA of waste management alternatives, including a comparison of recycling, composting, and landfill disposal in both conventional and bioreactor landfills (Barlaz, et al. 2003). As part of the LCA, a life cycle inventory was conducted of the benefits associated with resource recovery aspects of each waste management method.

The LCA utilized a computer model (USEPA's Integrated Solid Waste Management Decision Support Tool; ISWM-DST) to assess life cycle inventories for energy, 10 atmospheric pollutants, 17 waterborne pollutants, and generated solid wastes. The study concluded that when organic wastes from landfills were diverted for composting, there was a marked reduction in the energy benefit because of the reduced recovery of CH_4 from LFG. This trend occurred repeatedly for many of the other studied parameters. When conventional landfills were compared to bioreactor landfills, the life-cycle analysis concluded that the bioreactor landfill had increased overall environmental benefits with a substantial improvement in the area of energy recovery.

Barlaz, et al (2003) found that "across the board, the model suggests that the environmental performance of a bioreactor is superior to that of a traditional landfill for all LCA [life-cycle] parameters except CO [carbon monoxide]. When comparing greenhouse gas emissions (GHE), not only is the bioreactive favorable, but GHE are negative for the bioreactor and positive for a traditional landfill. In other words, diverting more organics from a bioreactor landfill to composting decreases the amount of GHE saved by capturing energy."

Christensen et al (2009) found that "considering the 100-year time frame, the overall life-time gas collection efficiency equals 50% for the conventional landfill and 80% for the bioreactor. All of the landfill scenarios but one (LAN1-0) had a negative GWF [global warming factor], which means that they all contributed with a saving with respect to GHG. The only exception was waste disposed directly in a conventional landfill equipped with a flare but no energy recovery. The results also show that for residual waste a bioreactor landfill was better than a conventional landfill with respect to GHG savings. The main difference was the maximized electricity production and the reduction in uncontrolled emissions of CH_4 from the bioreactor landfill. It should be underlined that carbon storage was a critical factor which influenced the results significantly by providing savings between 141 and 261 CO_2-eq. tonne^{-1}."

5.9 OTHER BENEFITS OF BIOREACTOR LANDFILLS

Bioreactors have a significant demand for liquids. Leachate recirculation alone cannot provide the needed moisture to achieve the target moisture content for a bioreactor landfill, i.e., field capacity or approximately 40 percent moisture by wet weight. The use of surface water or groundwater resources may not be feasible or could be in short supply in a particular area. As a result, bioreactor landfills can create additional opportunities for the landfill owner/operator for the disposal of alternative liquid wastes from industrial and commercial facilities and biosolids from agricultural operations and wastewater treatment. Hence, bioreactor landfills may be able to the reduce the demand on already strained publicly-owned treatment works (POTWs) that are at or near maximum capacity, and provide an alternative to current land disposal approaches (e.g. land application of sludges) that are facing increased regulatory control and public opposition.

5.10 ENERGY RECOVERY

During the life of a bioreactor landfill, the overall quantity of LFG generated per unit of waste (LFG yield) is expected to be the same or slightly higher than that of a conventional Subtitle D landfill operation (excluding the effect of the increased waste disposal tonnages because of more rapid settlement). However, in a bioreactor landfill, this quantity of LFG is expected to be generated at an accelerated rate when compared to a conventional Subtitle D operation (as shown in Figure 5-1). The peak LFG generation (and recovery rate) will be higher for a bioreactor landfill, and the landfill will remain at or near this higher peak for a longer period of time.

Bioreactor landfills require the installation of a GCCS sooner than conventional landfills for two reasons: 1) odor control resulting from increased LFG generation rates and 2) compliance with Clean Air Act (CAA) Maximum Achievable Technology (MACT) requirements under 40 CFR Part 63, Subpart AAAA. The MACT rule requires that a GCCS be installed before initiating liquids addition and start up 180 days after initiation or within 180 days after reaching 40 percent moisture. As such, no bioreactor landfill, as defined by USEPA, can be developed without early installation of GCCS and enhanced gas capture systems to meet MACT and New Source Performance Standards (NSPS) requirements under 40 CFR Part 60, Subpart WWW.

The GCCS must be sized to accommodate the increased LFG generation and peak LFG flows, and likely will include a combination of horizontal and vertical LFG collectors installed in conjunction with liquids delivery systems. In fact, an entirely new, horizontal plane-based LFG collection system has been designed and installed on a bioreactor landfill in Louisville, Kentucky, where LFG generation is three to four times that of a typical "dry tomb" landfill (Hater, et al., 2007). This improved design of the wellfield has allowed the site to achieve environmental compliance while at the same time collecting a significant amount of gas beyond what would normally be expected from a conventional landfill.

In order to complete a comparative analysis of bioreactor versus conventional, "dry tomb" type landfills, SCS Engineers (SCS, 2007) completed a study in which a conventional landfill scenario was evaluated as a baseline, which included continued disposal of all U.S. waste in a "dry tomb" type landfill. This baseline was contrasted with a scenario that assumed that 50 percent of the U.S. waste in the future would be disposed in a bioreactor landfill.

For waste in-place information, the analysis took the 40 percent increase in per capita tons of MSW disposed per year as identified by USEPA (2009) and applied that rate to the U.S. Census Bureau population projections through 2050 in order to develop a hypothetical bioreactor landfill, which received 50 percent of the U.S. waste from 2010 through 2050 (U.S. Census, 2004). The total tonnage of MSW disposed of in the super-landfill over the 40-year period was approximately 59 billion tons.

LFG generation rate estimates for the Baseline and Bioreactor scenarios were developed using the USEPA's first-order decay rate LFG emissions model (LANDGEM). Three (3) separate model runs were completed for the landfill: one for the baseline and two for the bioreactor scenario (one for the bioreactor and the second for the "dry tomb" landfill of the same size, each with 50 percent of the waste stream identified above). A value of 50 percent of the waste stream placed in a bioreactor is meant as a conservative estimate of the impact of bioreactors on the waste stream based on current obstacles in developing these projects. In practical application, this percentage could be higher, but certain impediments would need to be removed or minimized for this scenario to come to fruition. A summary of the model inputs is provided in Table 5-1 (SCS, 2007).

The projected differences in LFG generation between the bioreactor landfill and the "dry tomb" landfill were accounted for by altering the refuse decay rate constant ("k" value) of the refuse. The selection of "k" values for the various model runs was determined by considering default values prescribed by the USEPA and predicted values for bioreactor landfills from ongoing studies.

Because a bioreactor landfill is specifically designed to accelerate refuse degradation and LFG production, a "k" value of 0.16 was selected for use in the bioreactor model run based on industry experience with bioreactor landfills. USEPA's *Compilation Air Pollutant Emission Factors* (AP-42) document (Section 2.4 on landfills) (USEPA, 1997) sets forth a "k" value of 0.04 for wet climates and 0.02 for dry climates. A "k" value of 0.04 was selected for use in the dry-type model run (i.e., typical MSW landfill in a wet climate). As such, the 0.16 "k" value represents more than a four-fold increase in refuse degradation over the dry-type landfill.

A "L_o" value of 100 cubic meters per Megagram (m^3/Mg) was selected for use in the model runs for both landfill types. A "L_o" value of 100 m^3/Mg represents the value prescribed by AP-42 for use with MSW landfills (USEPA, 1997). GCCSs were assumed to be installed at both the bioreactor and dry-type landfill scenarios in the study. GCCSs at both hypothetical landfills were assumed to have a collection efficiency of 85 percent.

	Baseline	Bioreactor Landfill	
	Dry-Type Landfill	Bioreactor Portion	Dry-Type Portion
Total Waste in-place (billion tons)	58,966	29,483	29,483
Decay rate constant (1/year)	0.04	0.16	0.04
Methane Generation Rate (m^3/Mg)	100	100	100

Table 5-1. Comparative LFG Model Inputs

Methane generation was calculated over a 40-year landfill operational and post-closure care life covering the U.S. population projections from 2010 to 2050. Annual CH_4 recovery estimates were summarized for each year of the study. Recovered CH_4 was estimated to be equal to the amount of collected LFG (50% of the 85% portion of generated LFG). This calculation also was used to estimate the CH_4 recovery potential for each of the landfill types and convert those values into million metric ton of CO2 equivalent (MMTCE) of GHG reductions.

What is most significant in comparing these two scenarios is that, although both landfills reach their peak CH_4 production in the year following closure, the bioreactor scenario shows that the methane (energy) recovered is much higher than disposal of the same amount of waste in a conventional landfill. However, within 10 years after closure, the bioreactor scenarios show lower CH_4 recovery, and this trend continues through the post-closure care life of the landfill.

In addition, the recovered CH_4 potential was converted into a corresponding energy potential, assuming a BTU content of 500 BTUs/scf (i.e., approximately 50% methane). Electricity generation capacity (MW) was calculated by combining the BTU rate with a typical heat rate for LFGTE equipment (10,500 BTU/KWh) to arrive at MW. A summary of the comparative model results is presented in Table 5-2 (SCS, 2007).

	Baseline 100% to Conventional LF k=0.04 Lo = 100	Bioreactor 50% to Bioreactor LF k=0.16 Lo = 100	Net Increase in Recovered Energy	Percent Increase (%)
Peak Methane Recovery (MMTCE)	1,637	2,138	501	31
Total Methane Recovery over 40 years (MMTCE)	30,242	42,913	12,671	42
Peak Heat Recovery (MM BTU/min)	214,202	279,639	65,437	31
Total Heat Recovery (MM BTU/min)	3,956,263	5,613,850	1,657,587	42
Peak Power Production (MW)	20,400	26,632	6,232	31
Average Power Production (MW) (40 years)	8,910	12,701	3,791	43

Table 5-2. Comparative LFG Modeling Results

As shown above, by diverting 50 percent of the nation's MSW to a bioreactor landfill over 40 years, the U.S. can increase its electricity generation capacity (in MW) by up to 43 percent. In addition, bioreactor landfills would provide for an almost 42 percent increase in GHG reductions over conventional landfills.

Overall, bioreactor landfills could create long-term (40-year average) additional electrical capacity of approximately 12,701 MW. This amount could offset the use of approximately 286 million tons of coal that is enough to power more than eight million homes (USEPA, 2010).

This energy could also provide substantial assistance in bridging the 84,000 MW deficiency in electrical generating capacity needs predicted for the US over the next decade (NERC, 2007). The CH_4 recovery from bioreactor landfills could also provide for total GHG emission reductions in the amount of approximately 42,913 MMTCE. Of course, continued use of bioreactor landfills beyond 40 years would expand this benefit to even greater proportions.

5.11 BIOREACTOR ADVANTAGES/DISADVANTAGES

Designing landfills for enhanced waste decomposition as bioreactors has a number of advantages for landfill operators including:

- Increased/accelerated CH4 recovery and reduced GHG emissions;
- More predictable long-term landfill performance;
- Rapid stabilization of the waste to a stage where the ongoing leachate and LFG generation is environmentally acceptable without long-term collection and treatment activities;
- Controllable gas yields with a more economical production profile for energy recovery, and reduced wastage of gases;
- Leachate with a reduced treatment requirement;
- More efficient utilization of landfill disposal airspace that extends the useful life of existing landfills and reduces the need to construct new landfills;
- More revenue from existing landfills and reduced post-closure care costs;
- A reduction in the financial uncertainty associated with potential long-term liabilities;
- Increased land value after closure because of better waste stabilization and more options for land use including construction over refuse; and
- The acceptance of liquid wastes from outside the refuse mass as a means to generate additional revenue as well as to provide an alternate option for disposal of liquids, thereby reducing the burden on POTWs.

Bioreactor landfills are not without their potential disadvantages that could include the following:

- Increased cost for landfill design, construction, and operation;
- Increased potential for leachate and LFG impacts because of failure to properly design or operate the site for the increased generation rates of each (e.g., leachate outcrops and LFG generated odors);
- Potential slope stability issues for landfill liner designs that cannot accommodate the additional liquid head on the liner;
- Higher peak criteria pollutant emission rates from LFG combustion devices because of the increased LFG recovery rates; and
- Limited leachate quantities for recirculation in dry climates and lack of other water supplies to supplement.

Each of these potential disadvantages can be minimized or eliminated by proper design, construction, and operation of the bioreactor landfill and associated environmental control systems.

5.12 CONCLUSIONS

Benson, et al (2007) and others found that "interest in the bioreactor approach was tepid initially due to concerns regarding the effectiveness of landfill lining systems and aversion to leachate production, which often resulted in groundwater contamination in unlined landfills. However, modern composite liners used for landfills limit leakage to miniscule amounts when properly installed (Foose et al., 2001; Bonaparte et al., 2002). Consequently, the introduction of water and/or the recirculation of leachate is now considered plausible and, in some cases, desirable (Pacey et al., 1999; Reinhart et al., 2002)."

"In addition to long-term risk reduction, there are several advantages to bioreactor landfills (Barlaz et al., 1990; Reinhart and Townsend, 1997; Pohland and Kim, 1999). Enhanced decomposition increases the rate of MSW settlement (Edil et al., 1990; El-Fadel et al., 1999); Hossain et al., 2003), which provides the landfill owner with additional airspace prior to closure (i.e., a greater mass of waste can be buried per unit volume of landfill) and limits the potential for settlement-induced damage of the final cover (Benson, 2000). Enhancing the rate and extent of decomposition also increases the rate of landfill gas production (Klink and Ham, 1982; Findikakis et al., 1988; Barlaz et al., 1990; Mehta et al., 2002), improving the viability of gas-to-energy options."

Bogner, et al (2007), working the IPCC, found that "other measures to reduce landfill CH_4 emissions include installation of geomembrane composite covers (required in the US as final cover); design and installation of secondary perimeter gas extraction systems for additional gas recovery; and implementation of bioreactor landfill designs so that the period of active gas production is compressed while early gas extraction is implemented."

Bioreactor landfills, through the addition of liquids into the refuse mass, will likely cause a decrease in methane emissions because of the increase in life-cycle gas capture and enhanced energy recovery scenarios. These GHG benefits are coupled with a variety of other environmental and waste management benefits, making bioreactor landfills a viable and maybe even preferred option to conventional landfills and other organics diversion options.

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6.0 USEPA GHG INVENTORY

6.1 BACKGROUND

Landfills have experienced declining greenhouse gas (GHG) emissions since 1990 despite increases in waste disposal, an important trend to consider on a long-term basis (which is critical from a climate change perspective) (United States Environmental Protection Agency [USEPA], 2010). The success that landfills have had in achieving GHG reductions reflects increased use by landfill operators of LFG recovery, collection, and landfill design and operations to reduce emissions. By USEPA's statistics, landfills have reduced GHG emissions by almost 15% between 1990 and 2008, the most recent inventory year (USEPA, 2010). This is despite managing 24% more refuse since 1990 (USEPA, 2009b). Few, if any other industries can demonstrate GHG reductions despite increases in production and throughput over this time period.

Landfill opponents claim that landfill greenhouse gas (GHG) emissions appear to be increasing since 2000 based on the 2007 inventory published by the USEPA (2009a) for 2007. The USEPA 2007 inventory shows an 8.7% increase in GHG emissions from 2000 to 2007. The increase in emissions during this seven-year period may be due in some part to the fact that during this same time period, the U.S. population increased by 7.2% (U.S. Census Bureau, 2010) and disposal in landfills increased by 6.5% (USEPA, 2009b). Landfills continue to do an excellent job at controlling landfill gas (LFG) emissions despite managing more of the country's wastes.

In fact, USEPA (2009a) stated that "from 1990 to 2007, net CH_4 [methane] emissions from landfills decreased by approximately 10 percent. This net CH_4 emissions decrease is the result of increases in the amount of landfill gas collected and combusted, which has more than offset the additional CH_4 generation resulting from an increase in the amount of municipal solid waste landfilled over the past 17 years. Over the past 6 years, however, the net CH_4 emissions have slowly increased, but have remained relatively steady since 2005." Further, the draft USEPA inventory (USEPA, 2010) notes that net methane emissions from landfills decreased 15% from 1990 to 2008 and also decreased from 2007 to 2008, and the 2008 emissions were calculated to be lower than both 2006 and 2007. As such, the suspected increases in landfill methane emissions due to increased waste disposal appear to have ended in 2005 and have stabilized since then.

6.2 ISSUES WITH THE USEPA INVENTORY

As with any national GHG inventory, USEPA made a series of assumptions regarding the landfill sector due to the lack of site-specific data on all landfills. These assumptions affect the numeric emission levels attributed to the landfill category in USEPA's most recent inventory (USEPA, 2010). Also, the national GHG inventory is always being updated and modified as new information or methodologies are developed. These modifications may affect certain years' emission numbers more than other years, thus comparing individual years can be difficult to do since different calculation methods may have been used. This is why the long-term GHG trends are more important than any short-term trends in the data. That is, 1990 versus 2008 is much more of an important time window than 2000 to 2007 or 2008.

There are specific methodologies in the USEPA's inventory that have created inaccuracies in the GHG emissions attributed to landfills. These issues are detailed below.

6.3 USE OF LFG GENERATION MODELS

The USEPA (2010) GHG inventory for landfills uses a LFG generation model as its underlying methodology for estimating the amount of methane being generated by municipal solid waste (MSW) landfills. The use of models such as this presents a large potential for error and inaccuracies in the calculations, as detailed below.

Based on the first-order decay model used by USEPA, there is a high degree of uncertainty in terms of the predicted LFG generation from any given landfill, which could result in significant error in the estimation of methane emissions from a specific landfill and from the landfill industry nationwide. There is no current method to compare model estimates with actual data from landfills on a broad basis, and thus no sure way to know if the model value used by USEPA is accurate. That is, generation is an unknown value, so the models cannot be verified for accuracy. The models are theoretical projections based on debatable assumptions.
The model has multiple variables that are very difficult to estimate or calculate with any accuracy to account for all of the different landfills, waste streams, and climate zones in the U.S. The use of default values for variables such as the "k" (refuse decay rate) and "L_o" (methane generation potential) is one of the main reasons the first order decay model can produce such a wide range of error. These multiple variables can be a compounding source for error and uncertainty.

There can be large discrepancies in the annual waste disposal amounts, one of the primary inputs to the model, particularly for time periods before scale house data (i.e., actual measured weights) were available for U.S. landfills. USEPA (2010) uses different estimating methods for determining waste quantities for different time horizons, again making year-to-year comparisons difficult. For example, for the 2007 study year, USEPA used data on waste generation from Arsova, et al (2008) and Columbia University, which provides higher estimates than data used in previous years, such as 2000. This creates an artificial difference in LFG generation estimate when comparing those two years, which could account for the apparent increasing trend in landfill GHG emissions.

6.4 COMPILATION OF NATIONAL LFG RECOVERY DATA

USEPA (2010) calculates methane emissions from landfills by comparing the actual volume of gas collected relative to the volume projected by LFG models for generation. This approach is flawed. First order decay models commonly over predict LFG generation in drier and moderate rainfall zones, which encompasses the majority of the U.S. This results in artificially high emission estimates because the methodology assumes all the uncollected gas is emitted.

USEPA (2009a) has stated that "the estimated landfill gas recovered per year was based on updated data collected from vendors of flaring equipment, a database of landfill gas-to-energy (LFGTE) projects compiled by LMOP [Landfill Methane Outreach Program]… and a database maintained by the Energy Information Administration (EIA) for the voluntary reporting of greenhouse gases. Based on the information provided by the EIA and flare vendor databases, the CH_4 combusted by flares in operation from 1990 to 2007 was estimated. This quantity likely underestimates flaring because these databases do not have information on all flares in operation." This same source of error exists for the 2008 inventory (USEPA, 2010).

USEPA clearly admits that their methodology underestimates gas recovered by flaring, thereby overestimating the amount of methane emissions. This source of error is significant because a large percentage of methane from LFG is combusted in flares as compared to other devices, such as engines.

To further compound this error, USEPA (2010) also notes that "given that each LFGTE project is likely to also have a flare, double counting reductions from flares and LFGTE projects in the LMOP database was avoided by subtracting emissions reductions associated with LFGTE projects for which a flare had not been identified from the emissions reductions associated with flares."

This assumption is not correct. There are numerous LFGTE plants that do not have flares, where the LFGTE equipment serves as the only control device(s). As such, USEPA has subtracted off real methane reductions that are occurring based on an incorrect assumption. Further, flares at LFGTE plants are not only used in a backup role. For most projects, the flares burn the excess gas that is collected but cannot be managed by the LFGTE equipment. It is common for LFGTE plants to wait until a sufficient quantity of excess gas exists before expanding the capacity of the LFGTE equipment.

6.5 METHANE DESTRUCTION EFFICIENCY

USEPA (2010) noted that "a destruction efficiency of 99 percent was applied to CH_4, recovered to estimate CH_4 emissions avoided." This value was applied to all types of control devices in use regardless of their relative ability to destroy methane.

According to the Solid Waste Industry for Climate Solutions (SWICS, 2007), the average methane destruction efficiency of LFG flares, based on real stack test data, is 99.96%, 99.97% for gas turbines, and 98.34 % for lean burn engines. Industrial boilers, which are also used to burn LFG, are expected to have methane destruction efficiencies similar to flares. If the appropriate source-specific data for methane destruction were used, the composite destruction efficiency would clearly be more than 99%. As such, and yet again, USEPA is underestimating the amount of methane destroyed by landfills, thereby overestimating the amount of methane emissions.

6.6 METHANE OXIDATION

USEPA (2010) continues to use a factor of 10% for the percentage of methane that is oxidized by landfill covers. They state that "the factor of 10 percent is consistent with the value recommended in the 2006 IPCC [Intergovernmental Panel on Climate Change] revised guidelines for managed and covered landfills. This oxidation factor was applied to the estimates of CH_4 generation minus recovery for both MSW and industrial landfills."

Methane oxidation occurs in various types of landfill covers, including simple soil covers, and converts a portion of the anthropogenic methane back into biogenic carbon dioxide. Current literature support methane oxidation rates at levels well above the 10% default value used by USEPA (2010) and IPCC (2006). Recent research data would suggest that the default value is understated and that methane oxidation in landfill covers is more on the order of 20 to 50% depending on the cover type (Chanton, et al., 2009). The use of more accurate and up-to-date methane oxidation values for landfill covers will reduce methane emissions further from those estimated by USEPA (2010) and IPCC (2006). The 10% value is from a study more than 10 years old and does not reflect the current research and field studies on this issue. The continued use of the 10% value results in a severe overestimation of landfill methane emissions.

For example, Bogner, et al. (2007), working for IPCC, has reported that "under circumstances of high oxidation potential and low flux of landfill methane from the landfill, it has been demonstrated that atmospheric methane may be oxidized at the landfill surface. In such cases, the landfill cover soils function as a sink (reduction) rather than a source of atmospheric methane." These data directly contradict USEPA's use of the 10% value.

6.7 CONCLUSIONS

USEPA should improve its GHG inventory method for landfills. Assumptions used for LFG generation modeling, LFG recovery estimates, methane destruction efficiency, methane oxidation, and carbon sequestration serve to overestimate landfill methane emissions in the U.S., according to several prominent experts in the field.

USEPA should also start using the data being collected as part of new GHG reporting rule (40 CFR Part 98, Subpart HH) for landfills. This reported data is expected to be more comprehensive in terms of the number of landfills included and more accurate due to monitoring and data quality requirements in the rule.

For example, Bogner, et al (1997) stated that "given the data to date, current U.S. regulatory models… which estimate CH_4 emissions strictly from theoretical models of CH_4 generation without consideration of field measurements of CH_4 emissions or CH_4 oxidation, should be reconsidered and replaced. The high observed rates of CH_4 oxidation also argue against geomembrane covers or control of gaseous emissions, because methanotrophic CH_4 oxidation is dependent on diffusion of atmospheric O_2 to the site of microbial activity."

Bogner and Matthews (2003) noted that "it is likely that the net emissions are biased high because of undercounting of recovery and underestimation of oxidation. It would not be unreasonable to add 50-100% to commercial recovery for most countries to account for flared CH_4."

Despite the flaws in the calculation methodology and an increase in waste disposed in landfills, methane emissions have decreased by approximately 15% from 1990 through 2008 as a result of increased use of sophisticated LFG collection and combustion devices.

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7.0 TIPPING POINT

7.1 BACKGROUND

According to the United Nations Framework Convention on Climate Change (UNFCCC, 2004) and the Intergovernmental Panel on Climate Change (IPCC, 2006), methane is identified as having a global warming potential (GWP) of 21 to 25 times that of carbon dioxide. In addition, methane is recognized as having greater impact on global climate change in the short-term than carbon dioxide because it has a shorter life-span in the atmosphere.

Some believe that the shorter-term GWP values are more important because there is a concern that the planet could reach a purported "tipping point" sooner than 100 years, which would represent a "point of no return" when it comes to warming of the earth. The concept of a tipping point is not a scientific fact and is often debated by climate change experts as to whether such a point will actually occur and when.

Thus far, the international and U.S. convention for evaluating greenhouse gas (GHG) emissions is to consider 100-year GWPs since the effects of global climate change are long-term in nature. This convention is also utilized in all U.S. federal regulatory GHG programs and state programs, including U.S. Environmental Protection Agency (USEPA) rules and regulations, Assembly Bill (AB) 32 in California, and all state and local GHG reporting requirements. International and federal policymakers have agreed upon uniform GWPs in order to standardize GHG control programs, and the consensus of the experts is that the 100-year GWPs are the most appropriate to use. Therefore, methane should not be treated any different than other GHGs in this regard.

7.2 NEAR-TERM METHANE REDUCTIONS

In reality, the solid waste industry and landfills in particular benefit from an analysis that places greater value on short-term reductions in GHG that may be lesser in amount of reduction but nearer to the present time in opposition to larger GHG reductions that will be achieved many years from now. Some landfill opponents believe otherwise, but, in truth, landfills are the only major industry sector with declining GHG emissions since 1990 despite increases in waste disposal (USEPA, 2010). By USEPA's statistics, landfills have reduced GHG emissions by almost 15% between 1990 and 2008, the most recent inventory year (USEPA, 2010). This is despite managing 24% more refuse since 1990 (EPA, 2009b). Few, if any industries can demonstrate GHG reductions despite increases in production and throughput over this time period.

Because of regulatory and other programs that promote LFG recovery and utilization, such as the USEPA Landfill Methane Outreach Program (LMOP), the U.S. captures about 60% of the LFG captured worldwide although it generates only 24% of the worldwide methane (Themelis, 2008). It is clear U.S. landfills have already made huge strides toward achieving near-term methane reductions.

Assuming the 20-year GWP (72) for methane were to be applied to these reductions (which have been calculated at a GWP of 21), landfills have achieved 3.4 times more GHG reductions since 1990 beyond which current inventories give them credit. This analysis would suggest that landfills have done as much or more than any other industry to prevent the tipping point from being reached.

Analysis of existing emissions data from landfills also shows that USEPA has underestimated methane reduction from landfills, thus overestimating emissions of the same, because of the agency's GHG inventory method for estimating emissions from landfills. Data collected from operating landfills have shown that assumptions used for LFG generation modeling, LFG recovery estimates (USEPA, 2010), methane destruction efficiency (SWICS, 2007), methane oxidation (Chanton, et al, 2009), and carbon sequestration (USEPA, 2006; Weitz, et al, 2002) serve to overestimate landfill methane emissions in the U.S. Several prominent experts in the field have noted this fact.

For example, Bogner, et al (1997) stated that "given the data to date, current U.S. regulatory models… which estimate CH_4 emissions strictly from theoretical models of CH_4 generation without consideration of field measurements of CH_4 emissions or CH_4 oxidation, should be reconsidered and replaced. The high observed rates of CH_4 oxidation also argue against geomembrane covers or control of gaseous emissions, because methanotrophic CH_4 oxidation is dependent on diffusion of atmospheric O_2 to the site of microbial activity."

Bogner and Matthews (2003) noted that "it is likely that the net emissions are biased high because of undercounting of recovery and underestimation of oxidation. It would not be unreasonable to add 50-100% to commercial recovery for most countries to account for flared CH_4."

If the USEPA inventory were corrected to reflect more accurate data, landfill operations would be shown to have created even greater reductions in near-term GHG emissions over the last 20-year horizon. This success should be applauded and encouraged by support for increased use of efficient waste management methods such as landfill disposal, comprehensive LFG collection in disposal, and energy recovery from the LFG.

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