To: Jennifer Brady, Office of Resource Conservation and Recovery, EPA

From: Dr. Morton Barlaz, North Carolina State University; Christopher Evans, Adam Brundage, Victoria Thompson, Anne Choate, ICF International

Date: October 30, 2009

Re: WARM component-specific decay rate methods

The following memo provides a summary of proposed changes to the Waste Reduction Model (WARM) that will allow better customization and accuracy of the methane generation potential for waste materials at landfills and the associated landfill gas collection efficiency.

The attached memo from Dr. Morton Barlaz provides the technical background and methodology describing the development of the waste-component-specific decay rates for 4 main landfill types based on moisture conditions (dry, average, wet, and bioreactor). The attached memo also describes temporally weighted landfill gas collection system efficiency profiles for each of these 4 main landfill types based on 3 collection scenarios (typical collection, worst-case collection, and aggressive collection) . The final waste-component-specific decay rates and their associated landfill gas collection efficiencies per landfill type are listed in Table 7 through Table 10 of the attached memo.

It is important to note that the temporally weighted landfill gas collection efficiencies in this analysis are calculated over a 100-year time period. The rationale for selecting a 100-year approach is provided on page 4 of this memo, citing Barlaz et al. (2009). There are two important considerations in adopting this approach:

1. The 100-year timeframe used in this approach is different than the 30-year period used in EPA AP-42 and by the EPA's Landfill Methane Outreach Program (LMOP). ORCR may need to have internal discussions with the Office of Air Quality Planning and Standards (OAQPS) and the Landfill Methane Outreach Program (LMOP) to vet the 100-year timeframe used in this analysis.
2. In the past, ORCR has been asked to quantify annual emissions savings due to EPA programs; in these situations, a 30-year timeframe has been used. Previously, a phased approach was used to quantify GHG benefits over a 30-year timeframe based on the ultimate methane yield of organic components. Going forward, ORCR may need to assess the implications of adopting temporarily-weighted collection system efficiencies based on a 100-year timeframe if asked to quantify GHG benefits over a 30-year timeframe.

The overall goal of developing waste-component-specific decay rates that have varying collection system efficiency profiles depending on the landfill gas collection scenario is to enhance the flexibility and accuracy of WARM. Currently, WARM contains only one landfill type based on national average landfill characteristics. and assumes a default landfill gas collection efficiency default of 75%.[1] Once the waste-component-specific decay rate factors presented in the attached memo are implemented in WARM, users will be able to select specific landfill conditions (which greatly affect the landfill methane generation potential) and also select the associated landfill gas collection scenario to determine the overall landfill gas collection efficiency. Landfill gas collection system efficiency will therefore be calculated based on these two parameters, rather than a single collection system efficiency assumption. The resulting landfill emission factors generated for individual waste components will more accurately reflect the specific landfill characteristics and the collection efficiencies of specific collection scenarios.

[1] WARM users are currently able to modify this default value with an alternate percentage in the Excel version of the tool.

October 24, 2009

To: Chris Evans
Deanna Lizas
Victoria Thompson

From: Morton Barlaz

Re: Text to support WARM Model Defaults

The objective of this document is to describe the manner in which updated landfill gas collection efficiency factors were derived for use in WARM. These updates were based on: (1) improved estimates of temporally weighted gas collection efficiencies, and (2) incorporating waste-component-specific decay rates based on landfill moisture conditions.

The overall objective of WARM is to provide users with a simple tool to assess the environmental performance of alternatives for solid waste management. In the current implementation of WARM, the user is given relatively little flexibility to change key input parameters that affect environmental performance. The landfill component of WARM currently allows the user (1) to select whether a landfill has a gas collection system, (2) to input a single value for the gas collection efficiency, (3) and to specify whether the gas is used for electric power generation.

In practice, the landfill gas collection system efficiency does not remain constant over the duration of gas production. Rather, the gas collection system at any particular landfill is typically expanded over time. Usually, only a small percent (or zero) of the gas produced soon after waste burial is collected, while almost all of the gas produced is collected once a final cover is installed. Thus, the concept of a temporally weighted average gas collection efficiency was used to provide a better estimate of the gas collection system efficiency.

The timing and rate of gas production also depends upon how organic waste components degrade in landfills. This is related both to the moisture conditions of the landfill, and the different decay characteristics of each biodegradable waste component. Certain materials degrade quickly, producing large amounts of methane within the first few years of placement in a landfill. Other materials degrade more slowly, producing gas steadily over a long period of time. Generally speaking, all types of biodegradable waste degrade more rapidly the wetter the landfill conditions.

This concept is illustrated in Figure 1 where methane production is plotted for two values of the refuse decay rate, 0.04 yr^{-1} and 0.08 yr^{-1}. While the total volume of gas that is produced over 100 years is similar at the two decay rates, the rate at which this gas is produced varies significantly. This is important when considering the timing for the installation of a gas collection system.

Method to Calculate Temporally Weighted Landfill Gas Collection Efficiencies

In Figure 2, a gas collection scenario is imposed on the methane production rates presented in Figure 1. To develop Figure 2, the gas collection scenario described by Case 1 in Table 2 was assumed. At each time point, the methane production rate is multiplied by the assumed gas collection efficiency to calculate the rate of methane collection.

Figure 2a is presented based on twenty years of methane production while Figure 2b is presented based on 100 years of methane production. The step changes in collection in Figure 2 are an oversimplification as gas system coverage expands more gradually but these curves illustrate the appropriate manner in which to visualize gas collection. While all subsequent calculations were based on a 100-year time period, trends are easier to visualize in Figure 2a.

The rationale for the selection of a 100-year time period is summarized in Barlaz et al. (2009):

> For the analysis conducted here, it was assumed that the gas collection system would remain active for a 100 year period. The time required for 95% of gas production as a function of decay rate is presented in [Table 1] below. In reality, the period of gas collection system operation is unknown but not likely sensitive for this analysis. First, the system is likely to be operated as long as there is sufficient gas to run either a gas recovery system or a flare. This will depend on the quantity of waste in place and the operational decay rate. Second, the period of time required for post-closure care is evolving as the 30 year period specified in U.S. EPA landfill regulations is somewhat ambiguous (Barlaz et al., 2002; U.S. EPA 1991). It is most unlikely that owners will be allowed to walk away from landfills 30 years post-closure. One useful criterion might be to terminate a gas collection system when the oxidation capacity of the soil cover is sufficient to attenuate methane emissions after termination of a gas collection system. A review of soil methane oxidation capacity has recently been presented (Canton et al., 2009).

Ultimately, it is expected that landfill gas collection and control systems will be operated until methane emissions are close to zero.

Table 1: Time required for 95% of gas production as a function of decay rate.

	Bulk MSW decay rate (yr^{-1})				
	0.02	**0.04**	**0.07**	**0.1**	**0.15**
Year to 95% gas production (years)	>100	76	44	31	21.5

Source: Barlaz et al., 2009

An overall gas collection efficiency, referred to as a temporally-averaged gas collection efficiency, was calculated based on the total methane collected over 100 years divided by the total methane produced over 100 years. For the scenarios presented in Figure 2, the temporally averaged gas collection efficiency is 85.1% and 77.0%, for decay rates of 0.04 and 0.08 yr^{-1}, respectively. Additional results are presented in Table 2.

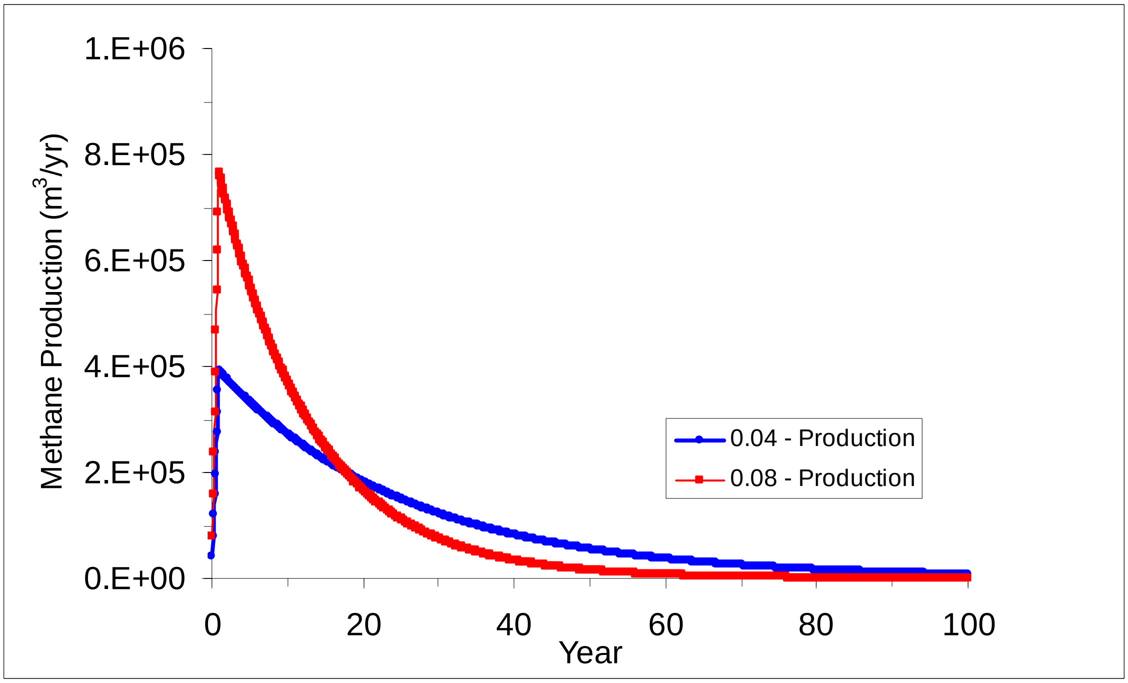

Figure 1: **Methane (CH_4) production as a function of the refuse decay rate (0.04 yr^{-1} or 0.08 yr^{-1}) for the burial of 100,000 metric tons (Mg) of waste in year 1. The ultimate yield for this waste was assumed to be 100 m^3 CH_4 per Mg.**

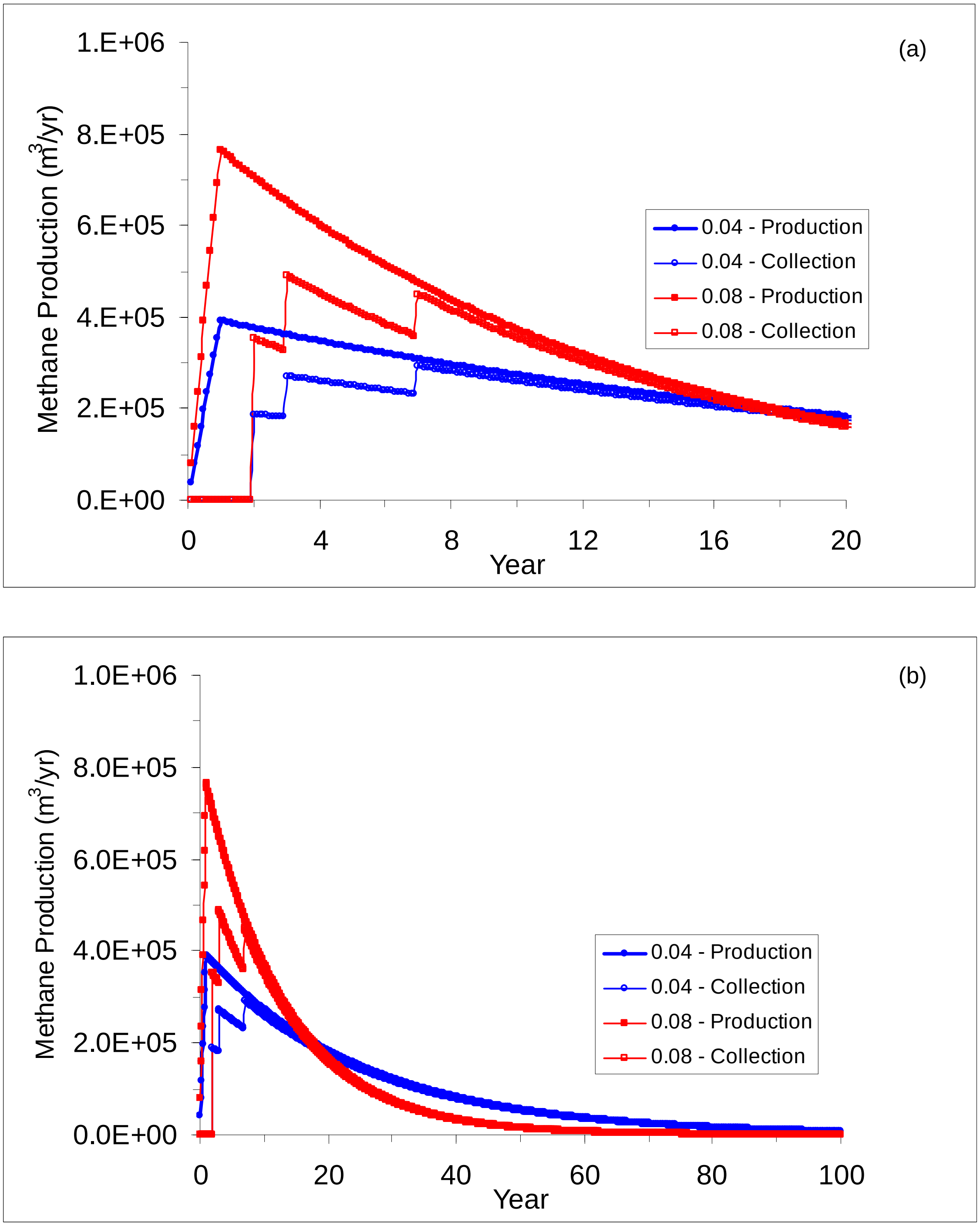

Figure 2: **Comparison of the methane production rate and methane collection rate for the gas collection scenario defined as Case 1 in Table 2 for (a) a 20-year timeframe and (b) a 100-year timeframe. Curves are presented at two decay rates (0.04^{-1} and 0.08 yr^{-1}) to illustrate that for the gas collection scenario described, more gas will be collected at the slower decay rate.**

Table 2: **Typical Gas Collection Scenarios and Selected Gas Collection Efficiencies Available to the WARM Model User**

Case	Gas Collection Scenario Description	Gas Collection Scenario	Landfill Gas Collection Efficiency (%) Decay Rate (yr^{-1})			
			0.02	0.04	0.08	0.12
AP-42	EPA default gas collection assumption (EPA 1998 AP-42)	All years: 75%	75.0	75.0	75.0	75.0
1	Phased in collection with improved cover	Years 1-2: 0% Year 3: 50% Years 4-7: 75% Years 8-100: 95%	89.2	85.1	77.0	na
2	Worst-case collection under EPA New Source Performance Standards (NSPS)	Years 0-5: 0% Years 6-7: 75% Years 8-100: 95%	84.8	77.9	64.5	na
3	Aggressive gas collection, typical bioreactor operation	Year 1: 25% Years 2-3: 50% Years 4-7: 75% Years 8-100: 95%	na	87.5	81.6	76.6

na = not applicable. For example, if a landfill is operated as a bioreactor, then the landfill owner should be expected to utilize collection scenario 3. However, aggressive gas collection (Case 3) is unlikely at landfills in an arid region although exceptions may exist.
Source: Based on the methodology provided in Barlaz et al. (2009), using updated landfill gas collection scenarios developed through consultations with landfill design experts.

To summarize:

- The gas collection efficiency varies with time as the gas collection system at a landfill is expanded
- A temporally-averaged gas collection efficiency was calculated from the total volume of methane collected divided by the total volume produced over a 100 year period
- The temporally-averaged gas collection efficiency is influenced by the rate at which a waste decomposes. More methane will be released (and not collected) for a waste that decomposes rapidly

A group of gas collection scenarios were defined in Table 2 to allow the WARM model user the flexibility to use a gas collection efficiency most representative of the specific landfill under study. Of course, if there is no gas collection system, then the gas collection efficiency would be zero. Even in this case, not all produced gas is emitted as some of the uncollected gas that passes through the landfill cover soil will be converted to carbon dioxide by methanotrophic bacteria. Oxidation of methane into carbon dioxide via the landfill soil cover is already accounted for in WARM.

The gas collection scenarios that are described in Table 2 were developed on the basis of literature reports and discussions with a number of landfill design experts in industry, academia and consulting. The values described are intended to represent the manner in which the average ton of waste buried in a landfill would be affected by the installation of a gas collection system. The first row in Table 2 represents the default AP-42 landfill gas collection efficiency (75%) value while Case 2 represents a worst case scenario in which a landfill owner remains in compliance with the New Source Performance Standards of the Clean Air Act. Case 1 represents typical gas collection while Case 3 represents aggressive gas collection as could be implemented at any landfill but is particularly important to implement at a bioreactor landfill where gas production starts earlier with the initiation of leachate or other liquid addition. It is recognized that no landfill will precisely meet the collection scenarios presented in Table 2 but these scenarios represent reasonable values for the evaluation of landfill performance. These scenarios were adapted from a recent study on temporally averaged gas collection efficiency (Barlaz et al. 2009).

While some landfill owners begin gas collection within months of waste burial using horizontal collection systems, this is not the general practice at this time and there is recognition that much of the gas from freshly buried waste is not collected. Thus, for Case 1, a collection efficiency of 0% was assumed for years 1 and 2. Thereafter, the waste is affected by gas collection as a collection system is installed and sections of the waste are under intermediate cover. The collection efficiencies used in Table 2 are based on the published data that are described in Barlaz et al. (2009). Published data suggest very high gas collection efficiencies once a final cover is installed. A number of experts were consulted to evaluate the year at which the average ton of waste comes under final cover. It should be recognized that at most landfills, the final cover is installed in stages so that even a landfill with a 50-year life will likely receive final cover over parts of the site much earlier. The time at which the average ton of waste comes under final cover varies considerably with the size of the landfill and state regulatory agency policy. Based on the consultations, values from 3 to 15 years were identified depending on a number of factors and it was judged that for an average of value, final cover placement after seven years of waste burial was reasonable.

As illustrated by Figure 2, the waste decay rate will also influence the temporally averaged gas collection efficiency. Thus, a method was developed to estimate the waste decay rate for individual waste components. This method is described below.

Method to Calculate a Waste-Component-Specific First Order Decay Rate

First order decay rates (k_{lab}) were calculated for several of the biodegradable components of municipal solid waste on the basis of laboratory experiments described in Eleazer et al. (1997) (see Table 3). To relate k_{lab} to a decay rate that was applicable at field-scale, it was assumed that the weighted average decay rate for a waste mixture should be equal to the bulk MSW decay rate. This is illustrated by Equation 1 where it was assumed that the bulk MSW decay rate was 0.04 which is the default value given in the U.S. EPA's database for regions that receive greater than 63 cm of rain annually (US EPA, 1998). To force the left side of Equation 1 to be equal to a constant, a correction factor, *f*, was introduced. The solver function in Microsoft Excel was used to search for *f*, which was constrained to be a positive value. Once *f* is determined, the field relevant decay rate, $k_{field,i}$, for each waste component (*i*) can be calculated from Equation 2.

$$f \times \sum_{i=1}^{n} k_{lab,i} \times (wt.\ fraction)_i = 0.04 \quad (1)$$

$$k_{field,i} = f \times k_{lab,i} \quad (2)$$

where *i* is the i^{th} waste component.

Table 3: Decay rates calculated from laboratory-scale reactors for individual refuse components

Component	Average[a] (yr^{-1})	Standard Deviation
Office paper	3.08	1.03
Grass	31.13	9.32
Branches	1.56	0.30
Newspaper	3.45	0.47
Corrugated Containers	2.05	0.07
Food	15.02	0.30
Leaves	17.82	4.28
Coated Paper	12.68	4.13

[a] Data are the average of four replicates except in the cases of branches and food waste where 1 and 2 reactors leaked and were excluded from the data set.
Source: dela Cruz & Barlaz (2009) Table 2, p. 7.

Equations 1 and 2 were applied to a range of decay rates and waste compositions. Waste composition data obtained from Staley and Barlaz (2009) are presented in Table 5. Using the waste composition data in Table 5, component-specific decay rates were calculated for individual waste components at a series of bulk municipal waste decay rates (Table 4) and the results, as derived from Equations 1 and 2, are presented in Table 6.

Table 4: **Municipal solid waste decay rates used to calculate waste-component-specific decay rates**

MSW Decay Rate (yr^{-1})	Selection Guidance
0.02	This is the default value given by EPA in AP-42 and applies to landfills that receive less than 25 inches of annual precipitation (U.S. EPA 1998)
0.04	This is the default value given by EPA in AP-42 and applies to landfills that receive greater than 25 inches of annual precipitation (U.S. EPA 1998)
0.08	This value is based on judgment and is intended to provide the user with a value between the AP-42 value of 0.04 for a traditional landfill and 0.12 for a bioreactor landfill. It should be used in landfills that are wetter than is typical due to either high precipitation or some leachate recirculation.
0.12	This value is based on judgment and is intended to represent a landfill that is operated as a bioreactor.

Table 5: National and State Average composition data used for the estimation of Field-Scale Decay Rate from Laboratory Data

	National Average [f] (%)				States Average [e] (%)						
	1990	1995	2000	2005	CA	DE	GA	MN	OR	PA	WI
Textiles (cotton)[a]	0.71	0.98	1.19	1.35	2.40	2.50	4.00	2.70	3.10	3.80	2.50
Wood (non-C&D)[b]	7.02	6.39	7.54	7.57	0.30	0.20	1.90	7.50	4.10	2.50	1.80
Food waste	12.10	13.53	15.57	17.12	14.80	9.30	12.00	12.40	15.70	12.10	10.30
Yard trimmings, Leaves[c]	7.18	5.30	2.96	2.94	2.65	2.61	1.08	0.92	2.53	2.09	0.48
Yard trimmings, Grass[c]	5.43	4.01	2.24	2.22	2.00	1.97	0.82	0.70	1.91	1.58	0.36
Yard trimmings, Branches[c]	5.30	3.91	2.19	2.17	1.95	1.92	0.80	0.68	1.86	1.54	0.36
Misc. organics	1.40	1.85	1.98	2.04	4.40	2.40	1.30	1.30	2.00	2.70	2.00
Newspaper	5.17	4.19	4.25	1.13	2.20	3.30	4.80	4.10	2.20	4.20	2.00
Office paper	4.97	4.79	4.69	4.05	2.00	1.80	3.40	3.10	1.80	3.70	1.40
Glossy paper	1.47	1.20	0.90	0.93	0.80	1.50	2.70	2.50	1.30	2.70	1.00
OCC/Kraft bags	7.26	6.60	5.46	5.30	6.80	7.80	11.00	6.90	3.30	8.40	4.20
Mixed Paper	11.66	14.52	13.95	13.78	3.70	3.00	6.40	8.50	6.50	4.60	5.00

[a] Roughly ~23.7% of textiles consumed in the U.S. from 2001-05 were made of cotton (Fiber Economics Bureau, 2006).
[b] Experiments to measure the decomposition of various types of wood are in progress.
[c] Based on relative contribution of grass (30.3%), leaves (40.1%) and brush (29.6%) in yard waste (Oshins and Block, 2000) .
[d] Other components are inert (e.g., plastic, glass) and therefore the total does not sum to 100%.
[e] The state composition data were adopted from Staley and Barlaz (2009)
[f] National average data were adopted from EPA waste characterization reports for various years (U.S. EPA 1990, 1995, 2000, 2005; as cited in dela Cruz & Barlaz, 2009)

Table 6: **Waste-component-specific decay rates as a function of bulk municipal waste decay rate**

Material	**Decay Rates (yr^{-1}) for Different Landfill Moisture Conditions**			
	Dry (k = 0.02 / yr)	Average (k = 0.04 / yr)	Wet (k = 0.08 / yr)	Bioreactor (k = 0.12 / yr)
Textiles (cotton)[a]	0.015	0.029	0.059	0.088
Wood (non-C&D)[b]	0.007	0.015	0.030	0.045
Food waste	0.072	0.144	0.288	0.432
Yard trimmings, Leaves	0.085	0.171	0.341	0.512
Yard trimmings, Grass	0.149	0.298	0.597	0.895
Yard trimmings, Branches	0.007	0.015	0.030	0.045
Newspaper	0.017	0.033	0.066	0.099
Office paper	0.015	0.029	0.059	0.088
Magazines/Third-class Mail	0.061	0.122	0.243	0.365
Corrugated Cardboard	0.010	0.020	0.039	0.059
Mixed paper, broad[c]	0.017	0.033	0.066	0.099
Mixed paper, residential[c]	0.017	0.034	0.069	0.103
Mixed paper, office[c]	0.031	0.063	0.126	0.189
Yard trimmings[d]	0.080	0.162	0.325	0.487
Mixed organics[e]	0.076	0.153	0.307	0.460

[a] Cotton was assumed to be equal to office paper.

[b] Wood was assumed to be equal to branches

[c] The three types of mixed paper were calculated as the weighted average of newspaper, office paper, magazines/third-class mail and corrugated cardboard based on the following composition:

	Broad	Residential	Office
Newspaper	24%	23%	21%
Corrugated Cardboard	48%	53%	5%
Office Paper	20%	14%	38%
Magazines/Third-class Mail	8%	10%	36%

[d] Yard trimmings is the weighted average of grass (30.3%), leaves (40.1%) and brush (29.6%) (Oshins and Block, 2000).

[e] Miscellaneous organics are assumed to be 48% food scraps and 52% yard trimmings where yard trimmings are defined in note d.

Finally, a temporally-averaged gas collection efficiency was calculated for each decay rate listed in Table 6 for each of the three gas collection scenarios presented in Table 2. These material categories were then matched to organic materials in WARM. These results are presented in Table 7 through Table 10. To implement this information in WARM, a user simply selects a gas collection scenario (Case 1, 2 or 3) and a bulk MSW decay rate (0.02, 0.04, 0.08 or 0.12 yr^{-1}). A look-up table that is internal to WARM then selects the appropriate gas collection efficiency for each waste component and this value is used in subsequent analyses.

Summary

In summary, these revisions will allow WARM to calculate a gas collection efficiency for each component of municipal solid waste. The gas collection efficiency is calculated in consideration of the rate at which individual waste components are estimated to decompose, and a gas collection scenario. Gas collection efficiency is calculated as the volume of methane collected divided by the volume of methane produced over 100 years. The gas collection efficiency decreases as the waste decay rate increases because more gas escapes uncollected for more rapidly degradable materials.

Table 7: Waste-component-specific decay rates and collection efficiencies for dry landfill moisture conditions (i.e., bulk MSW decay rate, k = 0.02 / yr)

WARM Material	Proxy Material (see Table 6)	Waste-Component-Specific Decay Rate (yr^{-1})	Collection Efficiency (%)		
			Case 1: Typical	Case 2: Worst-case	Case 3: Aggressive
Aluminum Cans	--	--	--	--	--
Steel Cans	--	--	--	--	--
Copper Wire	--	--	--	--	--
Glass	--	--	--	--	--
HDPE	--	--	--	--	--
LDPE	--	--	--	--	--
PET	--	--	--	--	--
Corrugated Cardboard	Old corrugated cardboard / Kraft bags	0.010	91%	88%	92%
Magazines/third-class mail	Average of newspaper and office paper	0.016	90%	86%	91%
Newspaper	Newspaper	0.017	90%	86%	91%
Office Paper	Office paper	0.015	90%	86%	91%
Phonebooks	Newspaper	0.017	90%	86%	91%
Textbooks	Office paper	0.015	90%	86%	91%
Dimensional Lumber	Wood (non-C&D)	0.007	91%	89%	92%
Medium Density Fiberboard	Wood (non-C&D)	0.007	91%	89%	92%
Food Scraps	Food waste	0.072	79%	67%	83%
Yard Trimmings	Yard trimmings	0.080	77%	65%	82%
Grass	Yard trimmings, Grass	0.149	65%	46%	73%
Leaves	Yard trimmings, Leaves	0.085	76%	63%	81%
Branches	Yard trimmings, Branches	0.007	91%	89%	92%
Mixed Paper, Broad	Mixed paper, broad	0.017	90%	86%	91%
Mixed Paper, Residential	Mixed paper, residential	0.017	90%	86%	91%
Mixed Paper, Office	Mixed paper, office	0.031	87%	81%	89%
Mixed Metals	--	--	--	--	--
Mixed Plastics	--	--	--	--	--
Mixed Recyclables	--	--	--	--	--
Mixed Organics	Mixed organics	0.076	78%	66%	82%
Mixed MSW	Bulk MSW	0.020	89%	85%	91%
Carpet	--	--	--	--	--
Personal Computers	--	--	--	--	--
Clay Bricks	--	--	--	--	--
Concrete	--	--	--	--	--
Fly Ash	--	--	--	--	--
Tires	--	--	--	--	--

-- = Not applicable for inorganic materials that do not degrade in landfills.

Table 8: Waste-component-specific decay rates and collection efficiencies for average landfill moisture conditions (i.e., bulk MSW decay rate, k = 0.04 / yr)

WARM Material	Proxy Material (see Table 6)	Waste-Component-Specific Decay Rate (yr^{-1})	Collection Efficiency (%)		
			Case 1: Typical	Case 2: Worst-case	Case 3: Aggressive
Aluminum Cans	--	--	--	--	--
Steel Cans	--	--	--	--	--
Copper Wire	--	--	--	--	--
Glass	--	--	--	--	--
HDPE	--	--	--	--	--
LDPE	--	--	--	--	--
PET	--	--	--	--	--
Corrugated Cardboard	Old corrugated cardboard / Kraft bags	0.020	89%	85%	91%
Magazines/third-class mail	Average of newspaper and office paper	0.031	87%	81%	89%
Newspaper	Newspaper	0.033	87%	80%	89%
Office Paper	Office paper	0.029	87%	82%	89%
Phonebooks	Newspaper	0.033	87%	80%	89%
Textbooks	Office paper	0.029	87%	82%	89%
Dimensional Lumber	Wood (non-C&D)	0.015	90%	86%	91%
Medium Density Fiberboard	Wood (non-C&D)	0.015	90%	86%	91%
Food Scraps	Food waste	0.144	66%	48%	74%
Yard Trimmings	Yard trimmings	0.162	63%	44%	72%
Grass	Yard trimmings, Grass	0.298	48%	23%	62%
Leaves	Yard trimmings, Leaves	0.171	62%	42%	71%
Branches	Yard trimmings, Branches	0.015	90%	86%	91%
Mixed Paper, Broad	Mixed paper, broad	0.033	87%	80%	89%
Mixed Paper, Residential	Mixed paper, residential	0.034	86%	80%	89%
Mixed Paper, Office	Mixed paper, office	0.063	80%	70%	84%
Mixed Metals	--	--	--	--	--
Mixed Plastics	--	--	--	--	--
Mixed Recyclables	--	--	--	--	--
Mixed Organics	Mixed organics	0.153	65%	46%	73%
Mixed MSW	Bulk MSW	0.040	85%	78%	88%
Carpet	--	--	--	--	--
Personal Computers	--	--	--	--	--
Clay Bricks	--	--	--	--	--
Concrete	--	--	--	--	--
Fly Ash	--	--	--	--	--
Tires	--	--	--	--	--

-- = Not applicable for inorganic materials that do not degrade in landfills.

Table 9: Waste-component-specific decay rates and collection efficiencies for wet landfill moisture conditions (i.e., bulk MSW decay rate, k = 0.08 / yr)

WARM Material	Proxy Material (see Table 6)	Waste-Component-Specific Decay Rate (yr^{-1})	Collection Efficiency (%)		
			Case 1: Typical	Case 2: Worst-case	Case 3: Aggressive
Aluminum Cans	--	--	--	--	--
Steel Cans	--	--	--	--	--
Copper Wire	--	--	--	--	--
Glass	--	--	--	--	--
HDPE	--	--	--	--	--
LDPE	--	--	--	--	--
PET	--	--	--	--	--
Corrugated Cardboard	Old corrugated cardboard / Kraft bags	0.039	85%	78%	88%
Magazines/third-class mail	Average of newspaper and office paper	0.063	80%	70%	84%
Newspaper	Newspaper	0.066	80%	69%	84%
Office Paper	Office paper	0.059	81%	71%	85%
Phonebooks	Newspaper	0.066	80%	69%	84%
Textbooks	Office paper	0.059	81%	71%	85%
Dimensional Lumber	Wood (non-C&D)	0.030	87%	81%	89%
Medium Density Fiberboard	Wood (non-C&D)	0.030	87%	81%	89%
Food Scraps	Food waste	0.288	49%	24%	63%
Yard Trimmings	Yard trimmings	0.325	45%	20%	61%
Grass	Yard trimmings, Grass	0.597	28%	6%	51%
Leaves	Yard trimmings, Leaves	0.341	44%	19%	60%
Branches	Yard trimmings, Branches	0.030	87%	81%	89%
Mixed Paper, Broad	Mixed paper, broad	0.066	80%	69%	84%
Mixed Paper, Residential	Mixed paper, residential	0.069	79%	68%	83%
Mixed Paper, Office	Mixed paper, office	0.126	69%	52%	76%
Mixed Metals	--	--	--	--	--
Mixed Plastics	--	--	--	--	--
Mixed Recyclables	--	--	--	--	--
Mixed Organics	Mixed organics	0.307	47%	22%	62%
Mixed MSW	Bulk MSW	0.080	77%	65%	82%
Carpet	--	--	--	--	--
Personal Computers	--	--	--	--	--
Clay Bricks	--	--	--	--	--
Concrete	--	--	--	--	--
Fly Ash	--	--	--	--	--
Tires	--	--	--	--	--

-- = Not applicable for inorganic materials that do not degrade in landfills.

Table 10: Waste-component-specific decay rates and collection efficiencies for bioreactor landfill moisture conditions (i.e., bulk MSW decay rate, k = 0.12 / yr)

WARM Material	Proxy Material (see Table 6)	Waste-Component-Specific Decay Rate (yr^{-1})	Collection Efficiency (%)		
			Case 1: Typical	Case 2: Worst-case	Case 3: Aggressive
Aluminum Cans	--	--	--	--	--
Steel Cans	--	--	--	--	--
Copper Wire	--	--	--	--	--
Glass	--	--	--	--	--
HDPE	--	--	--	--	--
LDPE	--	--	--	--	--
PET	--	--	--	--	--
Corrugated Cardboard	Old corrugated cardboard / Kraft bags	0.059	81%	71%	85%
Magazines/third-class mail	Average of newspaper and office paper	0.094	74%	60%	80%
Newspaper	Newspaper	0.099	74%	59%	79%
Office Paper	Office paper	0.088	76%	62%	81%
Phonebooks	Newspaper	0.099	74%	59%	79%
Textbooks	Office paper	0.088	76%	62%	81%
Dimensional Lumber	Wood (non-C&D)	0.045	84%	76%	87%
Medium Density Fiberboard	Wood (non-C&D)	0.045	84%	76%	87%
Food Scraps	Food waste	0.432	37%	12%	56%
Yard Trimmings	Yard trimmings	0.487	33%	10%	54%
Grass	Yard trimmings, Grass	0.895	17%	2%	45%
Leaves	Yard trimmings, Leaves	0.512	32%	9%	53%
Branches	Yard trimmings, Branches	0.045	84%	76%	87%
Mixed Paper, Broad	Mixed paper, broad	0.099	74%	59%	79%
Mixed Paper, Residential	Mixed paper, residential	0.103	73%	58%	79%
Mixed Paper, Office	Mixed paper, office	0.189	60%	38%	70%
Mixed Metals	--	--	--	--	--
Mixed Plastics	--	--	--	--	--
Mixed Recyclables	--	--	--	--	--
Mixed Organics	Mixed organics	0.460	35%	11%	55%
Mixed MSW	Bulk MSW	0.120	70%	53%	77%
Carpet	--	--	--	--	--
Personal Computers	--	--	--	--	--
Clay Bricks	--	--	--	--	--
Concrete	--	--	--	--	--
Fly Ash	--	--	--	--	--
Tires	--	--	--	--	--

-- = Not applicable for inorganic materials that do not degrade in landfills.

References

Barlaz, M. A., Chanton, J. P., & Green, R. B. Controls on Landfill Gas Collection Efficiency: Instantaneous and Lifetime Performance. Forthcoming in the Journal of the Air and Waste Management Association 2009.

Barlaz, M. A.; Rooker, A. P.; Kjeldsen, P.; Gabr, M. A.; Borden, R. C. A Critical Evaluation of Factors Required To Terminate the Post-Closure Monitoring Period at Solid Waste Landfills; Environ. Sci. & Technol. 2002, 36, 3457-3464.

Canton, J. P.; Powel son, D. K.; Green, R.B. Methane Oxidation in Landfill Cover Soils, is a 10% Default Value Reasonable?; Journal of Environmental Quality, 2009, 38: 654 - 663.

dela Cruz, F. B., & Barlaz, M. A. Estimation of a Component Specific Field-Scale Landfill Gas Decay Rate Constant Using Laboratory-Scale Decomposition Data. Forthcoming. 2009.

Eleazer, W.E.; Odle, W.S.; Wang, Y.S.; Barlaz, M.A. Biodegradability of municipal solid waste components in laboratory-scale landfills. *Environ. Sci. Technol.* **1997,** *31*, 911.

Fiber Economics Bureau. U.S. manufactured fiber, cotton and wool end use survey. Fiber Organon, **2006**, 77(10):187-204.

Oshins, C. and Block, D. Feedstock compositions at composting sites. *Biocycle* **2000,** *9*, 31-34.

Staley, B. F. and M. A. Barlaz. Composition of Municipal Solid Waste in the U.S. and Implications for Carbon Sequestration and Methane Yield. *J. Environ. Eng.* **2009,** 135, 10, p. 901- 909.

U.S., EPA. Part 258 - Criteria for Municipal Solid Waste Landfills, Code of Federal Regulations Title 40 Parts 257 and 258, **1991.**

U.S. EPA AP-42 Emission factors for Municipal Solid Waste Landfills- Supplement E. **1998,** Environmental Protection Agency.

U.S. EPA Facts and Figures 2007. **2008**, Environmental Protection Agency.