MEMORANDUM

To:	Henry Ferland, EPA/OSW
From:	Amanda Vemuri, Randy Freed
Date:	May 6, 2005
Re:	Revised Landfilling Emission Factors based on New WOODCARB Inputs
CC:	Dr. Mort Barlaz (NCSU), Anne Choate, Jeremy Scharfenberg

Introduction and Summary

This memorandum presents updated landfilling emission factors for paper and organic materials (other than leaves), based on a revised methodology for achieving a perfect (100%) carbon balance for these material types. In the context of reviewing the mass balance used to support the WOODCARB model used by USDA-Forest Service for simulating carbon flows associated with forest products, Dr. Morton Barlaz of NCSU recommended some revisions to the approach used to adjust his experimentally measured results to achieve a 100% carbon balance.

A perfect mass balance is important for WOODCARB, as that model attempts to track and account for all of the carbon that has been removed from forests. Achieving 100% carbon accounting has never been an objective for the Climate and Waste program, however, because we do not have to deal with carbon flows that are not addressed by GHG inventories, viz. biogenic CO_2 emissions. But given that it would be desirable for the C&W factors to be consistent with the WOODCARB methodology, and given that Dr. Barlaz's recommendation carries considerable weight, we suggest revising the C&W emission factors for organics accordingly.

This memo starts with a brief review of the mass balance elements, and then addresses the changes we propose for the various organic materials' emission factors, depending on which of the following two categories they fall into: "Outputs are Less Than Initial Carbon" (corrugated cardboard, wood/branches, office paper, and food discards) or "Outputs Exceed Initial Carbon" (newsprint, coated paper, grass, and [in the near future] leaves[1]). The memo concludes with a comparison of the newly calculated factors to the current emission factors.

In summary, for all of the materials except office paper (and mixed papers and phonebooks, which are composites for which office paper is a component), there are slight increases in the landfill net emission factors due to either a slight increase in methane yield or a slight decrease in landfill carbon storage. For office paper, our original methodology had included an adjustment to account for some missing methane (in the measured lab results); the new adjustment is less than the one we have been using since 1997, so the net effect is a reduction in the landfill emission factor.

[1] The revised methodology will be applied to the forthcoming lab results on leaves from Dr. Barlaz.

Background

The basic objective of the calculations is to make adjustments to the values derived from experiments conducted by Dr. Mort Barlaz and his colleagues[2] so that total carbon = 100% for all materials. To review, there are several elements in the mass balance:

- Initial carbon content (measured),
- Carbon output as methane,
- Carbon output as carbon dioxide, and
- Residual carbon (i.e., landfill carbon storage factor).

In a simple system where the only carbon fates are CH_4, CO_2, and carbon storage, you would expect

CH_4-C + CO_2-C + LF C = Initial C.

If the only decomposition is anaerobic, then CH_4-C = CO_2-C.[3] Mort Barlaz and his colleagues did not measure CO_2 outputs in their experiments. So, you would expect the system to be defined by

2 * CH_4-C + LF C = Initial C.

For wood/branches, corrugated cardboard, office paper, and food discards, the outputs (2 * CH_4-C + LF C) were less than the initial carbon (i.e., we had "missing" carbon). For newsprint, coated paper, grass, and leaves,[4] the outputs exceeded initial carbon. Since WOODCARB requires a mass balance that will allocate 100% of carbon, we made adjustments to force allocation such that

CH_4-C + CO_2-C + LF C = Initial C.

Although our original methodology did not require a perfect mass balance, we had identified situations where there was a significant imbalance and had made some adjustments to the values reported by Dr. Barlaz. As noted on pages 100-101 of the *Solid Waste Management and GHGs* report:

> *CH_4 recovery was below 85 percent of the CH_4 potential for five materials: coated paper, office paper, food discards, leaves, and branches. In using Dr. Barlaz's data, we needed to make a choice regarding how to allocate this missing carbon. We chose to assume that some of it had been converted to microorganism cell mass, and the remainder had been degraded. Dr. Barlaz*

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[2] Methane generation estimates are from Eleazer, W.E., W.S. Odle, III, Y.S. Wang, and M.A. Barlaz, 1997. "Biodegradability of municipal solid waste components in laboratory-scale landfills." Env. Sci. Tech. 31(3):911–917. Carbon storage and initial carbon content values are from Barlaz, M.A., 1998. "Carbon storage during biodegradation of municipal solid waste components in laboratory-scale landfills." Global Biogeochemical Cycles 12 (2), 373-380.

[3] The molar ratio of CH_4 to CO_2 is 1:1 for carbohydrates (e.g., cellulose, hemicellulose). For proteins, the molar ratio is 1.65 CH_4 per 1.55 CO_2, for protein as $C_{3.2}H_5ON_{0.86}$ (Barlaz et al. 1989). Given the predominance of carbohydrates, for all practical purposes, the overall ratio is 1:1.

[4] The references to leaves here is based on the published experimental data; this may change once new experimental data are available (expected to be within the next month).

> *postulated a higher CH_4 yield based on assumptions that (1) 5 percent of the carbon in cellulose and hemicellulose (and protein in the case of food discards) that was degraded was converted into the cell mass of the microbial population; and (2) 90 percent of the carbon-containing compounds that were degraded but not converted to cell mass were converted to equal parts of CH_4 and CO_2. . . . We decided, in consultation with Dr. Barlaz, to use the "corrected yields" for leaves, branches, and office paper because we believed that these values were more realistic than the measured yields.*
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> The last sentence includes two footnotes:
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> *(1) The corrected yield was not available for coated paper/magazines. For food discards, even though the CH_4 potential recovery percentage was lower than 85 percent, we used the measured yield, as shown in column "b." We made this choice for food discards because the "corrected yield" for food discards was greater than the maximum possible yield (shown in column "e" of the exhibit). Dr. Barlaz had calculated the maximum possible yield for each material based on the CH_4 yield if all of the cellulose, hemicellulose, and protein in the material (1) decomposed and (2) was converted to equal parts of CH_4 and CO_2.*
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> *(2) Note that EPA's Office of Research and Development (ORD) uses the same data as the basis for its estimation of CH_4 yields. In that analysis, ORD does not use "corrected" values for materials with low CH_4 recovery, but rather uses observed experimental values for all materials.*

Thus, for leaves, wood/ branches, and office paper, our existing emission factors already reflect an adjustment using a different (and more complicated) approach than the one adopted for WOODCARB and applied in the rest of this memo.

Table 1 provides the revised values. The specifics of our approach for the revised calculations are described below.

Outputs are Less Than Initial Carbon

For wood/branches, corrugated cardboard, office paper, and food discards, we assumed that the "missing" carbon had exited the experiment as equal molar quantities of CH_4 and CO_2. We thus increased the CH_4-C (with respect to the measured values) as follows:

(Initial C – LF C)/2 = CH_4-C

As before, we assumed that CO_2-C = CH_4-C so that the total carbon outputs are equal to the initial carbon content. The adjustments accounted for "missing" carbon of 6%, 2%, 17%, and 7% for wood, corrugated cardboard, office paper, and food discards respectively. The adjustments affect the methane yields for these materials (and "Paper – average") as seen in columns C (Fraction carbon released as CH_4), D (Fraction carbon released as CO_2), and E (Total fraction released as landfill gas) of Table 1.

Outputs Exceed Initial Carbon

For newsprint, coated paper, grass, and leaves, the outputs (2 * CH_4-C + LF C) exceeded the initial carbon content. Based on conversations with Dr. Barlaz, we had decided that the best way to resolve the mass balance discrepancy in the case of leaves was to assume that the measurements of initial carbon content and methane mass were accurate. Thus, we calculate landfill carbon storage as the residual of initial content minus (2 * CH_4-C). This adjustment, applied to the newsprint, coated paper, and grass categories, reduces their carbon storage values, shown in column F (Fraction of carbon stored) and column G (Fraction of dry matter stored) of Table 1. As noted earlier, no changes were made to leaves at this time since additional new information on this material type is expected soon.

Landfill Emission Factors

Updates to the methodologies for calculating methane yield and carbon sequestration in landfills resulted in relatively minor changes in landfilling emission factors for the paper types and organics. The material type with the largest change in emission factor was office paper, changing from a former net landfill emissions value[5] of 0.62 MTCE/ton to emissions of 0.48 MTCE/ton. Across all other organic and paper materials, the change in net emissions ranged from -0.02 MTCE/ton (for Mixed Office Paper) to +0.09 MTCE/ton (for Coated Paper – Magazines/Third-class mail). Table 2 presents the revised landfilling emission factors compared to the current landfilling emission factors for the material types discussed above.

With the new calculations, the methane yield for wood/ branches, corrugated cardboard, and food discards increased slightly resulting in slight increases in the net emissions for these material types. For wood/ branches, for which the measured methane yield had been adjusted in the original emission factors, the new adjustment results in slightly higher methane emissions than the old one. For office paper, the methane yield decreased. The original emission factor for this material also included an adjustment, but the new calculation results in a lower net emission.

Landfill carbon storage decreased for coated paper, newspaper, and grass, resulting in slight increases in net emissions for these materials.

In Tables 3 and 4 we compare the revised and former landfill methane emissions and landfill carbon sequestration values for the material types discussed above. Finally, in Table 5 we present a comparison of the net landfill emissions for all paper types and organic materials including the difference between the old and new values.

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We welcome your thoughts on these new emission factors. Please feel free to contact us if you would like more information or would like to discuss this.

[5] The ensuing discussion and the values shown in the tables are for the "national average landfill," i.e., national average landfill gas and energy recovery conditions.

Table 1: Updated Values for Methane Generation and Landfill Carbon Storage

Updated Values						
A	***B***	***C***	***D***	***E***	***F***	***G***
Carbon Source	**Methane released (gm CH_4/ dry gm)**	**Fraction C released as CH_4**	**Fraction C released as CO_2**	**Total fraction released as landfill gas**	**Fraction of carbon stored**	**Fraction of dry matter stored**
Wood (=branches)	0.041	12%	12%	23%	77%	38%
Newspaper	0.049	10%	10%	20%	80%	39%
Corrugated cardboard	0.100	22%	22%	45%	55%	26%
Office paper	0.142	44%	44%	88%	12%	5%
Coated paper	0.055	16%	16%	32%	68%	23%
Food scraps	0.197	42%	42%	84%	16%	8%
Grass	0.094	21%	21%	42%	58%	26%

Table 2: Comparison of Revised and Former Landfilling Emission Factors for Key Paper and Organic Material Types

Landfilling of Post-Consumer Material (GHG Emissions in MTCE/Ton)			
Material	**Revised Net Emissions**	**Former Net Emissions**	**Difference**
Corrugated Cardboard	0.09	0.08	0.015
Coated Paper	-0.03	-0.12	0.092
Newspaper	-0.19	-0.21	0.022
Office Paper	0.48	0.62	-0.144
Food Discards	0.19	0.17	0.016
Grass	0.03	0.01	0.022
Wood (=branches)	-0.09	-0.10	0.013

Table 3: Comparison of Revised and Former Landfill Methane Factors for Key Material Types

Landfilling of Post-Consumer Material (GHG Emissions in MTCE/Ton)			
Material	**Revised Landfill CH_4**	**Former Landfill CH_4**	**Difference**
Corrugated Cardboard	0.32	0.31	0.01
Office Paper	0.54	0.69	-0.15
Food Discards	0.21	0.19	0.02
Wood (=branches)	0.11	0.10	0.01

Table 4: Comparison of Revised and Former Landfill Carbon Sequestration Factors for Key Material Types

Landfilling of Post-Consumer Material (GHG Emissions in MTCE/Ton)			
Material	**Revised Landfill Carbon Sequestration**	**Former Landfill Carbon Sequestration**	**Difference**
Coated Paper	-0.20	-0.29	0.09
Newspaper	-0.34	-0.36	0.02
Grass	-0.09	-0.12	0.02

Table 5: Comparison of Revised and Former Landfilling Emission Factors for all Paper and Organic Material Types

Landfilling of Post-Consumer Material (GHG Emissions in MTCE/Ton)				
Category	**Material**	**Revised Net Emissions**	**Former Net Emissions**	**Difference**
Paper and Wood	Corrugated Cardboard	0.09	0.08	0.015
	Coated Paper	-0.03	-0.12	0.092
	Newspaper	-0.19	-0.21	0.022
	Office Paper	0.48	0.62	-0.144
	Phonebooks	-0.19	-0.21	0.022
	Textbooks	0.48	0.62	-0.144
	Dimensional Lumber (=branches)	-0.09	-0.10	0.013
	Medium-density Fiberboard	-0.09	-0.10	0.013
Other Organics	Food Discards	0.19	0.17	0.016
	Yard Trimmings	-0.13	-0.15	0.011
	Grass	0.03	0.01	0.022
	Leaves*	-0.29	-0.29	0.000
	Branches	-0.09	-0.10	0.013
Mixed Paper	Broad Definition	0.09	0.10	-0.009
	Residential Definition	0.07	0.07	0.002
	Office Paper Definition	0.14	0.15	-0.016

*The leaves category is shaded since the updates did not impact this material type in this round.