MEMORANDUM

To:	Sara Hartwell (EPA/OSW), Jennifer Brady (EPA/OSW), Tom Wirth (EPA), Melissa Weitz (EPA), Kim Klunich (EPA), Ken Skog (USDA), and Dennis Jackson (Environment Canada)
From:	Sarah Shapiro, Veronica Kennedy, and Randy Freed
Cc:	Dr. Mort Barlaz (NCSU), Anne Choate (ICF), Deanna Lekas (ICF), Susan Asam (ICF)
Date:	April 21, 2008
Re:	Revised Data for Landfill Carbon Storage in Yard Trimmings and Coated Paper, and Implications for Waste Management GHG Emission Factors and US GHG Inventory

In this memo we present revised estimates of data from Dr. Mort Barlaz and his colleagues on the carbon storage of grass, leaves, and coated paper in landfills. Dr. Barlaz's data informs multiple projects including the waste management greenhouse gas emission factors for the U.S. and for Environment Canada, the Landfilled Yard Trimming and Food Scraps analysis for the *Inventory of U.S. Greenhouse Gas Emissions and Sinks*, and WOODCARB landfill carbon storage, which is used in the harvested wood products section of the U.S. Greenhouse Gas Inventory.

Dr. Barlaz[1] and his colleagues published carbon storage factors (CSFs, measured in mass of carbon sequestered per dry mass of waste component) in 1998 for various municipal solid waste components including grass, leaves, branches, food, coated paper, old newsprint, old corrugated containers, and office paper. However, Dr. Barlaz and one of his graduate students[2] recently found an error in some of the original calculations for grass, leaves, and coated paper in his earlier experiments. Correcting the error changed the values for CSFs that are used to calculate the various emission factors listed above.

This memo provides recalculated factors for grass, leaves, and coated paper, and describes the approach we used for the recalculations. We start by reviewing the initial results from the 1998 paper and subsequent mass balance adjustments, and then describe our recent modifications to incorporate the corrected experimental results. Finally, we review the specific implications of the changes for each of the projects that use these data.

1. Initial Results and Adjustments

Each project uses data derived from a series of anaerobic decomposition experiments performed in a simulated landfill by Dr. Barlaz and colleagues. The initial focus of the experiments was on methane generation. Subsequent papers evaluated long-term carbon storage (*i.e.*, the residual carbon after the decomposition process was complete). The experimental data could be used to establish a mass balance for carbonaceous waste materials disposed in landfills.

[1] Barlaz, M.A., 1998, "Carbon storage during biodegradation of municipal solid waste components in laboratory-scale landfills," Journal of Global Biogeochemical Cycles, 12(2): 373-380.

[2] Memo dated February 28, 2008.

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

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

If the only decomposition is anaerobic, CH_4-C = CO_2-C. Dr. Barlaz and his colleagues did not measure CO_2 outputs in their experiments. So, the system can be defined by

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

This perfect mass balance relationship was not found for any of the materials. For branches, boxes, and office paper, the outputs were less than the initial carbon (*i.e.*, there was "missing" carbon in the outputs). For newsprint, coated paper, grass, and leaves, the outputs exceeded initial carbon.

We made adjustments to force a mass balance in order to allocate 100% of the initial carbon. This allocation requires that

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

1.1. Outputs are Less Than Initial Carbon

For branches[3], boxes, and office paper, we assumed that the "missing" carbon had exited the experiment in the form of CO_2 (*e.g.*, through aerobic decomposition prior to the onset of anaerobic decay). We thus increased the CO_2-C so that the total carbon outputs are equal to the initial carbon content. This adjustment only comes into play for the USDA-FS modeling of harvested wood products, where a complete mass balance is tracked on all carbon.

1.2. Outputs Exceed Initial Carbon

For newsprint and coated paper, the outputs (2 * CH_4-C+ LF C) exceeded the initial carbon content. Based on conversations with Dr. Barlaz, we decided that the best way to resolve the mass balance discrepancy in the case of these materials 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), i.e., we scaled down the measured CSF.

Exhibit 1 provides the recalculated values for grass, leaves, and coated paper using the original data as reported in 1998. For leaves, no adjustment was needed because the outputs were less than the carbon inputs.

[3] Branches serve as a proxy for wood in the HWP analysis.

Exhibit 1. Values for initial carbon content and carbon storage factor from Barlaz (1998). The outputs for both grass and coated paper were larger than the inputs, so the proportion of carbon stored was adjusted.

Carbon Source	ICC	CSF	Adjusted CSF	Proportion of Carbon Stored (before adjustment)	Proportion of Carbon Stored (after adjustment)
Grass[1]	44.87%	0.32	0.30	71%	68%
Leaves[2]	41.60%	0.30	n/a	72%	n/a
Coated Paper[1]	34.30%	0.34	0.26	99%	75%

[1] For grass and coated paper, the outputs exceeded the inputs and required the mass balance adjustment.
[2] The source of this data is Barlaz (2005) in a letter report to Randy Freed on June 29, 2005. Dr. Barlaz corrected the leaves data that had been previously reported in Barlaz (1998).

2. Updates to CSF for MSW Components

Earlier this year, a computational error was found in the calculations used to account for carbon in the "seed" used to inoculate the experimental waste materials with anaerobes. The error impacted the CSFs for grass, leaves, and coated paper, and the CSFs have now been updated to correct the error. This section outlines those changes. Exhibit 2 provides data from Dr. Barlaz and his colleagues' 2008 memo. The values for all other remaining municipal solid waste components were not changed.

Exhibit 2. Values for initial carbon content and carbon storage factor as corrected by Dr. Barlaz in 2008. The output for coated paper is larger than the inputs, so the proportion of carbon stored was adjusted downward. No further adjustment was made for grass and leaves, as discussed below.

Carbon Source	ICC	CSF	Adjusted CSF	Proportion of Carbon Stored (before adjustment)	Proportion of Carbon Stored (after adjustment)
Grass	44.87%	0.24	n/a	53%	n/a
Leaves[1]	45.50%	0.39	n/a	85%	n/a
Coated Paper[2]	34.30%	0.27	0.26	79%	75%

[1] This experiment was repeated by Dr. Barlaz and a CSF of 0.3 was measured in a later experiment, after it was previously measured as 0.47. Dr. Barlaz suggested using the average of 0.47 and 0.30 or 0.385.
[2] For coated paper, the outputs exceeded the inputs and required the mass balance adjustment so we used a CSF of 0.26.

2.1. Grass

The 2008 recalculation lowered the CSF for grass from 0.32 to 0.24. Since all other values remain the same, less carbon is stored. The outputs (2 * CH_4-C+ LF C) had originally exceeded the inputs (*i.e.*, were greater than 100 percent) and required the mass balance adjustment described above. With this recalculation, outputs are now are less than the inputs because of the significant reduction in carbon stored in landfills. Therefore, no further mass balance adjustment is necessary since the outputs are less than the inputs (*i.e.*, less than 100 percent), and in our revised calculations we use the carbon storage factor for grass as reported in Dr. Barlaz's 2008 memorandum.

2.2. Leaves

Leaves had been the most challenging material as far as closing the mass balance in Dr. Barlaz's original data because the residual carbon content originally reported was higher than the initial carbon content. In 2005, Dr. Barlaz updated the experiment on the decomposition of leaves and provided that data to Randy Freed in a letter.[4] Since then, we have used the 2005 data for leaves. The 2008 data update provided a new CSF for the 1998 values for leaves (though they do not affect the 2005 values). The 2008 correction has the effect of changing the residual carbon to be less than initial carbon for the 1998 results. So at this point, there are two valid sets of data for leaves.

Dr. Barlaz recommended averaging the two (2005 and 2008) leaves experiments, as both samples and tests were legitimate and the variation illustrates heterogeneity in this waste stream. The 2008 recalculation, and subsequent averaging, increased the CSF for leaves from 0.30 (based on the 2005 experiment alone) to 0.39 (based on both experiments and using the corrected values for the 1998 experiment). The values are shown in Exhibits 1 and 2. The outputs (2 * CH_4-C+ LF C) are still less than the inputs, so no mass balance adjustment is needed for the CSF.

2.3. Coated Paper

For coated paper, the 2008 recalculation lowered the CSF for coated paper from 0.34 to 0.27. As with the original results, with the corrected values the carbon outputs (2 * CH_4-C+ LF C) exceed the inputs, and require the mass balance correction. Therefore, we resolve the mass balance discrepancy as described above in the *Outputs Exceed Initial Carbon* section. After correcting the mass balance, the revised CSF is 0.26 (see Exhibit 2).

3. Implications for Programmatic Calculations

3.1. WAste Reduction Model (WARM)

WARM is a tool for waste managers to identify greenhouse gas savings through alternative waste disposal technologies. The recalculated CSF for grass and leaves changed the corresponding emission factors along with the emission factors for yard trimmings and mixed organics.

Based on national average conditions for landfill gas management, the landfill emission factors for leaves, grass, yard trimmings, mixed organics, and mixed paper are provided in Exhibit 3. Grass changes from a slightly negative emission factor (*i.e.*, net storage) to slightly positive (*i.e.*, net emissions). The emission factor for leaves changes in the opposite direction, becoming more negative (greater net storage). These updates have not yet been incorporated into WARM.

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[4] Barlaz, M.A., 2005, "Decomposition of Leaves," Letter report to Randy Freed, ICF International, June 29, 2005.

Exhibit 3. Values for the landfill emission factor for grass, leaves, yard trimmings, and mixed organics. The values using the original data are provided for comparison.

Carbon Source	New Landfill Emission Factor (MTCE/short ton)	Old Landfill Emission Factor (MTCE/short ton)
Grass	0.05	-0.01
Leaves	-0.16	-0.05
Yard Trimmings	-0.09	-0.06
Mixed Organics	0.05	0.06
Mixed Paper	0.09	0.10

3.2. Environment Canada GHG Waste Management Emission Factors

Environment Canada maintains a set of Canadian GHG emission factors structured similarly to WARM, which we discussed above. This set of emission factors will hopefully inform Canadian waste managers about greenhouse gas emissions in the same way WARM informs American waste managers. The recalculated CSF for grass and leaves changed the emission factor for landfilling yard trimmings. Based on the national average gas collection conditions in Canadian landfills, the baseline emission factor calculated using Dr. Barlaz's original data was -0.15 tonne CO_2e/tonne yard trimmings. When we apply Dr. Barlaz's updated CSFs, the emission factor yard trimmings is -0.17 tonne CO_2e/tonne yard trimmings. Dr. Barlaz's updated coated paper CSF changed the emission factor for the other paper category from 0.69 to 0.70 tonne CO_2e/tonne paper. These changes have already been incorporated in the March 28, 2008 version of the spreadsheet.

3.3. Landfilled Yard Trimmings and Food Scraps

Landfilled Yard Trimmings and Food Scraps is a source category for emissions in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks*. The recalculated CSF for grass and leaves increased the carbon stock for this category by an average of 7 percent for each year of the inventory compared to the 2005 inventory. The 2005 carbon stock increased by 13 percent compared to the previous inventory. The recalculations were incorporated in the latest draft of the *Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2006*.

3.4. Harvested Wood Products

The USDA-FS modeling system for Harvested Wood Products uses carbon storage factors to calculate net emissions from the "Changes in Forest Carbon Stocks" category in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks*. The CSF for coated paper contributes to the "HWP in Solid Waste Disposal Sites" total carbon storage. The recalculated CSF will decrease the amount of carbon stored for this product category. The recalculated value has not yet been incorporated into the modeling system.

Exhibit 4 shows the potential inputs for WOODCARB.

Exhibit 4. Updated values for methane generation and landfill carbon storage based on Barlaz (2008) for WOODCARB.

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**
Coated Paper	0.056	12%	12%	25%	75%	26%

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Please let us know if you have any questions or comments on these changes and the revised approach.