NC STATE UNIVERSITY

Dept. of Civil, Construction, and Environmental Engineering
Box 7908
Raleigh, NC 27695-7908
USA
919-515-7908 (fax)

October 27, 2008

To: Parties Interested in Carbon Sequestration from Municipal Solid Waste

From: Morton A. Barlaz

Re: Corrections to Published Carbon Storage Factors for Mixed Municipal Waste

In 1998, I published a paper entitled "Carbon Storage During Biodegradation of Municipal Solid Waste Components in Laboratory-Scale Landfills." The complete reference is at the end of this memo. The paper reports a carbon storage factor (CSF) for municipal solid waste of 0.22 gm C Stored/gm dry refuse. This factor was calculated from the mass of organic carbon removed from a set of four reactors filled with shredded residential refuse after refuse decomposition was complete. However, this number is incorrect because it includes both biogenic and fossil carbon. In this memo, the CSF has been recalculated in consideration of this issue, albeit with some uncertainty.

The mass or organic carbon entering the reactor was calculated from the dry mass of refuse and the % organic carbon. Unfortunately, the % organic carbon of the refuse used was not measured. As a result, the mass of carbon at the initiation of the experiment is estimated assuming a carbon content of 42% (dry weight basis). This value was selected because it was measured on another sample of residential refuse collected a few months later. In addition, this value appears to be reasonable. Bahor et al. (2008) suggest that 30% C is a reasonable average for the carbon content of MSW on a wet weight basis, and 30% C on a wet weight basis is equivalent to 37.5% on a dry weight basis at 20% moisture. The CSF calculation is described below.

The mass of organic carbon was divided into fossil and biogenic fractions by assuming that the initial carbon was 65% biogenic based on stack gas testing results presented in Bahor et al. (2008). From the dry mass of initial refuse, the % organic C and the % fossil C, the mass of fossil C entering a reactor was calculated. The mass of fossil C entering a reactor was assumed equal to the mass of fossil C leaving a reactor since fossil C (e.g. plastics, rubber) does not biodegrade.

The total C remaining in a reactor after decomposition was calculated from the dry mass after decomposition and the measured organic C for the decomposed refuse. The mass of this C that was biogenic was then calculated as the total C removed minus the total initial fossil C. Finally, the CSF was calculated as the biogenic C that remains after decomposition divided by the initial dry weight of refuse. The results of this calculation are summarized in Table 1 (column 2).

Initially, this calculation was repeated at a wide range of organic carbon contents. However, the result was a range that did not relate to the biodegradation of refuse. Specifically, carbon storage increased as the assumed initial carbon content decreased. Because this is illogical, CSFs are calculated for a narrow range of values with 42 % as an upper limit.

There is another way to estimate carbon storage that was proposed by Andrew Szurgot and Brian Bahor. Again assuming an initial carbon content of 42%, the fraction of the initial biogenic carbon stored is 28.5% for the reactor experiment. If it is assumed that 28.5% of the biogenic carbon is stored, then the CSF can be calculated at other assumed initial carbon contents. These values are also presented in Table 1 (column 3). Using this method, the CSF decreases as the initial %C decreases.

In addition to the fact that all results are based on one experiment, there is an additional factor that contributes to uncertainty. The decomposed refuse on which the total C was measured was not washed with acid prior to analysis. Therefore, any inorganic C present in the sample would be counted as organic C. I do not expect this error to be significant in consideration of other uncertainties. For any samples analyzed in my lab in the last few years, the inorganic C has been removed by acid washing prior to analysis as is standard procedure for this type of work.

Table 1 Corrected Carbon Storage Factors for MSW from Laboratory-Scale Experiment

Initial C (% of dry wt.)[a]	Carbon Storage – calculated as described in the text (Biogenic C Stored/Dry Refuse)	Carbon storage – calculated assuming that 28.5% of the initial biogenic C is stored (Biogenic C Stored/Dry Refuse)
37.5	0.094	0.069
40.0	0.085	0.074
42.0	0.078	0.078

a. The initial carbon concentration of the MSW tested is not known because the original sample was lost. The CSF was calculated for 42% C because this was measured on another sample of residential refuse.

Another Alternative for Calculation of Carbon Storage

I would like to point out one additional resource for estimation of carbon sequestration. The CSFs based on my original manuscript are presented in Table 2. (Notes that some of these values differ from the original manuscript as described in a memo issued on Feb. 28, 2008 and presented below for your convenience.) The values in Table 2 can be used with waste composition data to estimate a CSF. I did this for 11 statewide waste composition studies and estimated a CSF of 0.13±0.01 kg C dry kg refuse^{-1} (range 0.11 to 0.15 kg C dry kg refuse^{-1}). A manuscript on this topic has been submitted for publication. I am happy to provide it if desired.

While I cannot eliminate all of the uncertainty in CSFs, it is clearly below 0.22 and a value between 0.07 and 0.15 appears more reasonable.

Table 2 Carbon Storage Factors for MSW Components

Waste Component	Carbon (%)	Revised Carbon Storage Factor[a]
Grass	44.87	0.24
Leaves	49.4	0.47
Branches	49.4	0.38
Food	50.8	0.08
Coated paper	34.3	0.27
Old newsprint	49.2	0.42
Old corrugated containers	46.9	0.26
Office paper	40.3	0.05

a. Units are mass of carbon sequestered per dry mass of waste component.

Please feel free to contact me if you need any additional information and once again I apologize for errors in the initial publication.

References

Bahor, B., Weitz, K. and Szurgot, A., 2008, "Updated Analysis of Greenhouse Gas Emissions Mitigation from Municipal Solid Waste Management Options Using a Carbon Balance," Proc. 1st Global Waste Management Symposium, Copper Mountain, CO., Sept. 7-10.

Barlaz, M. A., 1998, "Carbon Storage During Biodegradation of Municipal Solid Waste Components in Laboratory-Scale Landfills," J. Global Biogeochem. Cycles, 12, 2, p. 373-80.

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February 28, 2008

To: Parties Interested in Carbon Sequestration from Municipal Solid Waste

From: Morton A. Barlaz

Re: Corrections to Previously Published Carbon Storage Factors

In 1998, I published a paper entitled "Carbon Storage During Biodegradation of Municipal Solid Waste Components in Laboratory-Scale Landfills." The complete reference is at the end of this memo. Recently, one of my Ph.D. students identified an error in equation 1 of this paper and as a result of that error, some of the published carbon storage factors (CSFs) are incorrect. The objective of this memo is to provide an explanation of the error and corrected CSFs.

In the study described in the manuscript, the amount of carbon stored was measured for individual components of municipal solid waste (MSW). A seed of decomposed refuse was used to initiate methane generation in the waste component reactors. The methane generation and carbon sequestration that were attributed to the seed were measured in a set of control reactors. The data for the control reactors were used to adjust the methane generation and carbon sequestration measured in the component reactors. Some waste component reactors were operated for a shorter period of time than the control reactors. As a result, there would be more background carbon sequestration in the waste component reactors that were operated for shorter periods of time due to undegraded seed material. However, equation 1 from the referenced manuscript contains the term Y_t/Y which results in less background carbon sequestration from the seed and this is incorrect. This error affects the CSFs for grass, leaves and coated paper.

$$CSF_i = \frac{C_{out} - (CSF_S \times W_S)\frac{Y_t}{Y}}{M} \quad (1)$$

Variables in equation 1 are defined as follows: CSF_i is the carbon storage factor for component i, C_{out} is the mass of carbon remaining after decomposition, CSF_S is the carbon storage factor for the seed, W_S is the mass of seed in a component reactor, Y_t is the average methane yield of the seed reactors at the time that the four component i reactors were dismantled, Y is the average final methane yield of the seed reactors, and M is the initial dry mass of component i in each reactor. The term Y_t/Y represents a correction factor on carbon storage attributable to the seed, signifying that some component reactors were dismantled prior to the seed reactors. The corrected equation is given as equation 2:

$$CSF_i = \frac{C_{out} - [((CSF_S + CSF_g) \times W_S)]}{M} \qquad (2)$$

where CSF_g represents the mass of carbon per gm of seed that was degradable but had not degraded because the waste component reactor was destructively sampled prior to conversion of the seed carbon into carbon dioxide and methane. All other terms are as in equation 1. CSF_g was calculated from the difference between the ultimate methane yield in the seed reactors and the methane yield at the time that a set of component reactors was destructively sampled as in equation 3:

$$CSF_g = [CH_4(s) - CH_4(s,t)] * 2 * 12 \text{ gm C mole C} / 22400 \text{ (mL/mole)} \qquad (3)$$

where $CH_4(s)$ is the ultimate methane yield of the seed, $CH_4(s,t)$ is the methane yield of the seed at the time when the waste component reactors were destructively sampled. The factor of two in equation 3 converts moles of methane to moles of methane plus carbon dioxide.

Based on equations 2 and 3, grass, leaves and coated paper have corrected CSFs that are presented in Table 1. These values should be used in place of the values in the 1998 publication. In addition, the carbon storage experiment for leaves was repeated in a later experiment and a CSF of 0.3 was measured.

Table 1 Carbon Storage Factors for MSW Components

Waste Component	Carbon (%)	Revised Carbon Storage Factor[a]	Original Carbon Storage Factor[a]
Grass	44.87	0.24	0.32
Leaves	49.4	0.47	0.54
Branches	49.4	0.38	0.38
Food	50.8	0.08	0.08
Coated paper	34.3	0.27	0.34
Old newsprint	49.2	0.42	0.42
Old corrugated containers	46.9	0.26	0.26
Office paper	40.3	0.05	0.05
MSW	42-50.2[b]	0.22	0.22

b. Units are mass of carbon sequestered per dry mass of waste component.
c. The initial C concentration of the MSW tested is not known because the original sample was lost. A value of 42.0% was measured on another sample of residential MSW while Tchobanoglous et al. report 50.2%.

Needless to say, I apologize for this error and am thankful that my Ph.D. student, Bryan Staley, discovered the error which gives me the opportunity to make the correction. I will contact the editor of the Journal of Global Biogeochemical Cycles to determine whether they wish to publish a short note on this error. Please feel free to contact me if you need any additional information. I can best be reached by email at barlaz@eos.ncsu.edu.

The complete reference is:

Barlaz, M. A., 1998, “Carbon Storage During Biodegradation of Municipal Solid Waste Components in Laboratory-Scale Landfills,” J. Global Biogeochem. Cycles, 12, 2, p. 373-80.