

# The Biogenic Carbon Cycle in Annual Crop-Based Products

Prepared for the Biogenic CO<sub>2</sub> Coalition

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by

Seungdo Kim and Bruce E. Dale

Department of Chemical Engineering and Materials Science

Michigan State University

3815 Technology Boulevard, Lansing, MI 48910

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## Preface

This report was commissioned by the Biogenic CO<sub>2</sub> Coalition for its use in petitioning the U.S. Environmental Protection Agency (EPA) for relief from including biogenic CO<sub>2</sub> emissions in two of the Clean Air Act's air permitting programs, namely: (1) the "Prevention of Significant Deterioration" (PSD) program for preconstruction review and approval of new and modified "major" stationary sources (*e.g.*, 40 CFR § 51.166), and the so-called "Title V" program for establishment of comprehensive operating permits for such sources (*e.g.*, 40 CFR Part 70). The Coalition seeks to exclude specifically those emissions of CO<sub>2</sub> resulting from combustion, fermentation, or microbial wastewater treatment of annual crop-derived plant biomass. The members of the Coalition are: American Bakers Association, American Farm Bureau, Corn Refiners Association, National Association of Clean Water Agencies, National Cotton Council, National Cottonseed Products Association, and National Oilseed Processors Association.

## Main Conclusions

Biogenic carbon, as defined in this report and as defined by essentially all other regulatory and advisory bodies, does not and in fact cannot increase atmospheric CO<sub>2</sub> levels. However, in the overall carbon cycle for crop-based products, it is possible for some changes in atmospheric carbon to occur because of changes in land-based carbon stocks. These changes in atmospheric CO<sub>2</sub> may be environmentally detrimental (increased atmospheric CO<sub>2</sub>), positive (decreased atmospheric CO<sub>2</sub>) or negligible (near zero). We have analyzed the changes in atmospheric CO<sub>2</sub> for four different industries: corn wet milling, corn dry milling, corn stover combustion and wastewater treatment. For the industries studied, we find that these changes are all positive. The cumulative effect of processing biogenic carbon at these facilities is to reduce atmospheric CO<sub>2</sub> levels.

## Introduction

This document focuses on biogenic CO<sub>2</sub> emissions from a facility processing or producing annual crop-based products. Annual crops include wheat, corn, soybeans and any other plant whose growth and harvest take place on an essentially yearly cycle. Biogenic CO<sub>2</sub> emissions from such a facility differ greatly from other CO<sub>2</sub> emissions, notably CO<sub>2</sub> emissions resulting from combustion of fossil fuels. *We define “biogenic carbon” as that portion of carbon flows in a processing facility that is derived via the fixation of atmospheric CO<sub>2</sub> into annual plant materials.* As documented below, this treatment of biogenic carbon is exactly the same as that adopted by international and national regulatory agencies, including the EPA, with the sole exception of a single paragraph in EPA’s Response to Comments document supporting its 2009 Endangerment Finding for greenhouse gas (GHG) emissions from motor vehicles<sup>1</sup> and the resulting regulation of emissions of biogenic CO<sub>2</sub> from motor vehicles<sup>2</sup> and industrial facilities<sup>3</sup>.

In 2009, when EPA made its seminal Endangerment Finding for motor vehicles, it declared in that single paragraph that: “First, all CO<sub>2</sub> emissions, regardless of source, influence radiative forcing equally once it reaches the atmosphere and therefore *there is no distinction between biogenic and non-biogenic CO<sub>2</sub>* regarding the CO<sub>2</sub> and other well-mixed GHGs ....” It is true that each molecule of carbon dioxide is equal in its capacity to influence radiative forcing in the atmosphere. However, EPA’s assertion is extremely misleading in the context of the Endangerment Finding. The assertion ignores the carbon life cycle outlined in Figure 1. The idea

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<sup>1</sup> U.S. Environmental Protection Agency, Endangerment and Cause or Contribute Findings for Greenhouse Gases Under Section 202(a) of the Clean Air Act: EPA’s Response to Public Comments, Volume 9: The Endangerment Finding, at 5 (Response 9-9, first paragraph) (2009) (EPA-HQ-OAR-2009-0171-11676). The Endangerment Finding appears at 74 Fed. Reg. 66496 (Dec. 15, 2009).

<sup>2</sup> U.S. Environmental Protection Agency, Renewable Fuel Standard Program (RFS2) Regulatory Impact Analysis (EPA Publication 420-R-10-006, 2010).

<sup>3</sup> 40 CFR Part 52

that all carbon dioxide in the atmosphere is identical is simply wrong and ignores the well-known difference between carbon stocks and flows<sup>4,5</sup>. Carbon released from a carbon stock such as soil, coal, oil or natural gas adds to net radiative forcing (i.e., to climate change), while carbon participating in a carbon flow does not increase net radiative forcing.

Indeed, life on earth would not be possible without the continuing carbon flow that produces all plant matter and sustains all other life. Life on earth would also not be possible without the radiative forcing effect caused by natural levels of atmospheric CO<sub>2</sub> that warm the planet to comfortable temperatures. The issue is not radiative forcing, which is essential for life on earth, the issue is increased radiative forcing caused by release of carbon stocks. In contrast to natural and essential levels of atmospheric carbon dioxide, increased radiative forcing may make the planet less habitable. We will demonstrate these facts by several examples.

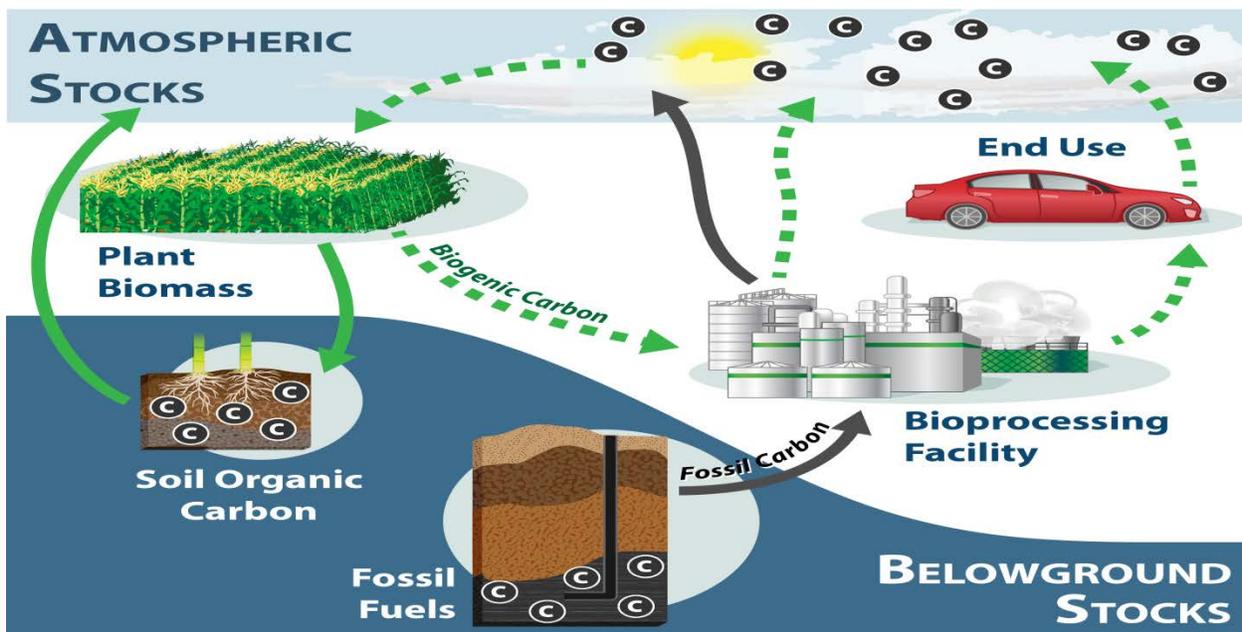
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<sup>4</sup> <http://epa.gov/epawaste/conserves/tools/warm/index.html> WARM Version 12, WARM Background and Overview. February 2012

<sup>5</sup> <http://epa.gov/epawaste/conserves/tools/warm/index.html> WARM Version 12, Forest Carbon Storage, p. 15 (box) (February 2012) (INSERT quotation from box).

## Understanding Carbon Stocks and Flows: A Figure and a Homely Comparison

The context for all the examples cited is Figure 1 below for carbon contained in annual crops. This figure illustrates the differences between carbon stocks and flows, which is essential to understanding this issue. Figure 1 outlines the overall process by which atmospheric carbon is fixed by plant material (corn in this case) and then processed into various products which are then used by humankind, releasing the carbon back into the atmosphere on a relatively short time scale. This figure applies to all of the specific processing systems described herein for annual crop products. Biogenic carbon flows are represented by the dashed green lines while carbon released from soil carbon stocks is represented by solid green lines and carbon released from fossil carbon stocks is represented by solid black lines.



**Figure 1** Generic diagram showing biogenic carbon flows and releases of carbon from soil and fossil fuel stocks

Before launching into detailed technical analyses, we wish to further explain the difference between carbon stocks and flows, since this point is so important. Perhaps a comparison with money in Mr. John Doe’s checking account might be most illustrative. It is true that every dollar in a checking account is equal and can be spent equally to meet John’s needs (*all carbon dioxide in the atmosphere is equivalent, according to the Endangerment Finding’s response-to-comments document*). But it is not true that each dollar spent has an equal impact on John’s financial health (*global climate*). If that dollar came from John’s monthly paycheck or “money flow” (*carbon flow within the biosphere*), then spending it does not affect John’s financial status (*global climate*). However, if that dollar in John’s account were borrowed or taken from a money “stock” (*taken from a carbon “stock”*) then spending it has a very different effect on John’s financial health (*global climate*). In contrast with spending a dollar from his monthly paycheck or “flow of dollars”, spending that borrowed dollar from a dollar “stock” creates a debt that John will have to repay.

This homely example illustrates a basic principle behind greenhouse gas accounting that has been widely recognized by international and national scientific and regulatory organizations and, indeed, by the EPA itself. The principle is that *biogenic carbon, as defined above, should not be counted in greenhouse gas accounting methodologies. However, the life cycle greenhouse gas emissions of products made from biogenic carbon may not be zero and can be affected by emissions from the land-use sector as shown in Figure 1.*

## Examples from the EPA Showing the Correct Use of Biogenic Carbon

### Accounting

Correct accounting for biogenic carbon is well-described in, for example, the EPA's recent (2012) Waste Reduction Model (WARM) and supporting documents. The purpose of WARM is to calculate GHG emissions reductions from different waste management practices via examining life cycle GHG emissions of alternative practices compared to a baseline scenario. The WARM Background and Overview document devotes almost an entire page (pg. 15) to explaining why biogenic CO<sub>2</sub> is not counted and the context for adopting that convention, namely that biogenic emissions (such as burning wood) "return to the atmosphere CO<sub>2</sub> that was originally removed by photosynthesis. In this case, the CO<sub>2</sub> emissions are *not* counted." (Emphasis added by the EPA in the original WARM document.)

The WARM document continues "On the other hand, CO<sub>2</sub> emissions from burning fossil fuels *are* counted..." (Again, emphasis added by the EPA in the original WARM document.) In making this distinction between biogenic carbon and fossil carbon, EPA points out that it is simply following the fundamental convention adopted by the United Nations Framework Convention on Climate Change (UNFCCC)<sup>6</sup> and the inventory methods developed by the Intergovernmental Panel on Climate Change (IPCC)<sup>7</sup>.

The WARM document continues by giving a number of specific applications of this general principle. For the process of **composting** (pg. 19), it states that "biogenic CO<sub>2</sub> emitted from these materials (leaves, brush, grass, food wastes and newspaper) during composting is not counted toward GHG emissions." For the process of **combustion** the document states (pg. 20)

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<sup>6</sup> [http://unfccc.int/essential\\_background/items/6031.php](http://unfccc.int/essential_background/items/6031.php)

<sup>7</sup> IPCC (2006) 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

“Nonbiogenic CO<sub>2</sub> emitted during combustion (i.e., CO<sub>2</sub> from plastics) is counted toward the GHG emissions associated with combustion, but biogenic CO<sub>2</sub> (i.e., CO<sub>2</sub> from paper products) is not.” For **landfilling**, the document points out, in the case of energy recovery from methane from a landfill, that: “Almost all of the captured methane is converted to CO<sub>2</sub>, but is not counted in this study as a GHG because it is biogenic.”

The unifying principle in all of the specific cases cited above is that atmospheric CO<sub>2</sub> can be affected by the change in carbon stocks, by not by biogenic carbon flows. If the focus is on the carbon in the products derived from annual crops (the dashed green arrows in Figure 1), then biogenic carbon cannot increase atmospheric CO<sub>2</sub> levels.

## Why the Confusion over Carbon Accounting?: Three Different Viewpoints

However, confusion sometimes arises when the system of Figure 1 is analyzed from different viewpoints. Three different viewpoints are widely used:

1. The **biogenic carbon** viewpoint, already discussed. Biogenic carbon is represented by dashed green lines in Figure 1.
2. The **life cycle** viewpoint, which considers all of the carbon flows shown in Figure 1, including biogenic carbon flows as well as flows from fossil and soil carbon stocks (solid black and green lines, respectively).
3. The **bioprocessing facility** viewpoint, which only considers the flows coming into and out of it.

It is obvious that increased carbon stocks (such as increased forest carbon sequestration, carbon storage in the soil, and carbon in long term landfill storage, see Exhibit 3 on pg. 11 of WARM) will remove carbon from the atmosphere and will thereby reduce overall atmospheric CO<sub>2</sub> levels. In contrast, decreased carbon stocks (decreased soil carbon or decreased fossil fuel stocks) add to atmospheric CO<sub>2</sub> levels. If increased carbon stocks are desirable from an atmospheric CO<sub>2</sub> perspective, then decreased carbon stocks must be undesirable from that same perspective. *We simply must treat carbon stocks differently than carbon flows in atmospheric CO<sub>2</sub> accounting.* Unfortunately the Endangerment Finding's response-to-comment document does not distinguish between carbon stocks and flows.

In contrast, the life cycle assessment (LCA) thinking that is increasingly used by EPA and international organizations to understand and regulate system-wide environmental impacts does indeed distinguish between stocks and flows. This report's authors (Drs. Kim and Dale)

have published extensively on the use of LCA to understand and follow greenhouse gas (GHG) emissions from agricultural and other systems<sup>8</sup>. We apply that LCA background to this report, including our analysis of the Biogenic Accounting Factor (BAF) used by the EPA. BAF is a facility-centric approach to calculating carbon flows and is an example of Viewpoint #3 described above. Therefore the BAF is a truncated or partial analysis, not a system-wide analysis such as LCA. Properly used, however, BAF can give results consistent with LCA, as we show below.

LCA is a tool to estimate environmental impacts associated with a product (or service) system from cradle to grave<sup>9</sup> and is widely used in policy making processes to estimate GHG emissions associated with a product system. For example, EPA used LCA to determine GHG emissions associated with renewable fuels for the Renewable Fuel Standard Program (RFS2). In the RFS2, GHG emissions associated with renewable fuel supply chains (i.e., from biomass production, transportation, fuel processing, distribution and combustion in a vehicle) are estimated. Consistent with the recommendation of international agencies such as the IPCC and EPA's own carbon accounting standards such as those described in the WARM model discussed above, biogenic carbon emissions in the renewable fuel systems such as combustion CO<sub>2</sub> emissions for renewable fuels (e.g., ethanol, biobased diesel, etc.) are not included in the RFS2. (see Box 1 below). Note that the quote in Box 1 also distinguishes clearly between net carbon fluxes caused by changes in "biogenic carbon reservoirs" or stocks of carbon, as we have explained previously and illustrated in Figure 1.

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<sup>8</sup> See the Curriculum Vitae appended to this report.

<sup>9</sup> International Organization for Standardization, ISO 14040: Environmental Management – Life Cycle Assessment – Principles and Framework. 2006

Box 1. Excerpts from Renewable Fuel Standard Program (RFS2) Regulatory Impact Analysis

*“...Combustion CO<sub>2</sub> emissions for ethanol and biomass-based diesel were based on the carbon content of the fuel. However, over the full lifecycle of the fuel, the CO<sub>2</sub> emitted from biomass-based fuels combustion does not increase atmospheric CO<sub>2</sub> concentrations, assuming the biogenic carbon emitted is offset by the uptake of CO<sub>2</sub> resulting from the growth of new biomass. As a result, CO<sub>2</sub> emissions from biomass-based fuels combustion are not included in their lifecycle emissions results. Net carbon fluxes from changes in biogenic carbon reservoirs in wooded or crop lands are accounted for separately in the land use change analysis as outlined in the agricultural sector modeling above.”*

In contrast, the “biogenic accounting factor” (BAF) has been developed by EPA to estimate biogenic CO<sub>2</sub> emissions from stationary sources (or facility, process, etc.) that might increase net atmospheric CO<sub>2</sub> concentrations<sup>10</sup>. BAF is facility oriented, while LCA is product (or service) supply chain oriented. Despite the different system approaches, both systems account for the biogenic carbon flow. However, the two systems are quite different in how to handle biogenic carbon emissions. In LCA, biogenic carbon emissions associated with land use in the agriculture sector are assigned to the feedstock production stage, while those biogenic carbon emissions are assigned to the stationary source in BAF, even though *those carbon emissions do not actually occur in that processing facility*.<sup>11</sup> LCA has clear boundaries between lifecycle

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<sup>10</sup> USEPA, Accounting Framework for Biogenic CO<sub>2</sub> Emissions from Stationary Sources, 2011.

<sup>11</sup> The snapshot emissions released from stationary sources (e.g., fossil carbon emissions from stationary sources) may well be potential subjects for Clean Air Act regulation. But, if the same assumption used in RFS2 (i.e. the biogenic carbon emitted is offset by the uptake of CO<sub>2</sub> resulting from the growth of new biomass) were applied to

stages (e.g., feedstock production, fuel processing, etc.) so that LCA results are an accumulation of individual (or “snapshot”) emissions released from each lifecycle stage (e.g., stack emissions, tailpipe emissions, etc.).

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the BAF system, then biogenic CO<sub>2</sub> emissions from stationary sources would not be seen as affecting the atmospheric CO<sub>2</sub> concentrations.

## Carbon Dioxide Emissions from Four Different Systems: Results of Calculations from Three Different Viewpoints

We have used all three viewpoints described above to calculate the atmospheric CO<sub>2</sub> impacts of four different processing systems based on annual crops such as corn, wheat, soybeans and so forth. The four different processing facilities include:

1. Corn wet milling plant
2. Corn dry milling plant
3. Corn stover combustion plant
4. Wastewater treatment plant

The details of our calculations are given in the Appendices. The results of these calculations are summarized in Table 1 below.

**Table 1 Net Atmospheric Carbon Emissions from Four Processing Facilities from Three Different Viewpoints**

	Biogenic Carbon	Life Cycle <sup>¶</sup> [pound C per pound biogenic C processed]	BAF Factor
Corn Wet Milling	0.0	-0.004 (± 0.001)	- 0.012 (±0.0004)
Corn Dry Milling	0.0	-0.004 (± 0.001)	- 0.001 (±0.0004)
Corn Stover Combustion	0.0	-0.01	-0.01
Wastewater Treatment	0.0	-0.05	-0.05

<sup>¶</sup>Including only biogenic carbon

In all four cases analyzed here, the net carbon emissions as measured by the life cycle and BAF methodologies are actually slightly negative: *carbon dioxide is therefore removed from the atmosphere, not added to it when biogenic carbon is processed in these industries.* Biogenic

carbon, as defined here and as defined by all major regulatory agencies including EPA except for the single case of EPA's 2009 Endangerment Finding, is zero for all four industries.

## Appendix A. Net Atmospheric Carbon Emissions from Four Processing Facilities

### A1. Corn wet milling facility for ethanol production

This example shows the biogenic carbon cycle in a corn wet milling facility producing ethanol. The process data except for the wastewater treatment facility are obtained from the corn wet milling industry (three companies contributed information). Arithmetic average values of the process data are used in the calculations due to the confidentiality concerns. A life cycle biogenic carbon balance for corn ethanol produced in the corn wet milling facility shows that the net effect is that about 10 ( $\pm 3.5$ ) pounds of biogenic carbon per acre are sequestered, even when the CO<sub>2</sub> emissions from combustion of the fuel ethanol is taken into account. BAF for corn wet milling facility is  $-0.012$  ( $\pm 0.0004$ ). In other words, corn ethanol in an illustrative wet mill is not just “carbon neutral” but the entire cycle of corn ethanol production by wet milling actually sequesters net atmospheric carbon into soil carbon.

**Life cycle biogenic carbon balance.** The biogenic carbon cycle is estimated for a hypothetical corn wet milling facility, to which several counties in Iowa (as seen in Table 2) supply corn grain. Table 2 shows the percentage of corn grain supplied from each county and the county level tillage practices. Tillage is a key factor influencing the soil organic carbon dynamics. The weighted average corn yield in these counties is 138 bushels per acre<sup>12</sup>.

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<sup>12</sup> The National Agricultural Statistics Service, USDA, <http://www.nass.usda.gov/>.

**Table 2 Corn grain supply and tillage practices<sup>13</sup>**

County	Percentage of corn grain supplied	Tillage practice (%)		County	Percentage of corn grain supplied	Tillage practice (%)	
		No tillage	Other practices <sup>¶</sup>			No tillage	Other practices <sup>¶</sup>
Audubon	1.9%	53%	47%	Johnson	1.8%	33%	67%
Black Hawk	2.4%	9%	91%	Jones	2.5%	10%	90%
Boone	2.8%	4%	96%	Linn	2.5%	13%	87%
Carroll	3.0%	12%	88%	Marshall	2.4%	61%	39%
Cass	2.1%	41%	59%	Mills	1.6%	55%	45%
Cedar	2.5%	24%	76%	Monona	2.9%	23%	77%
Cherokee	2.4%	2%	98%	Montgomery	1.5%	61%	39%
Clinton	3.1%	12%	88%	Palo Alto	2.8%	7%	93%
Crawford	3.4%	45%	55%	Plymouth	3.5%	7%	93%
Delaware	3.1%	5%	95%	Pottawattamie	4.0%	53%	47%
Franklin	3.4%	2%	98%	Sac	2.8%	1%	99%
Grundy	2.5%	10%	90%	Scott	1.8%	18%	82%
Hamilton	3.4%	3%	97%	Shelby	3.0%	56%	44%
Hancock	3.2%	2%	98%	Sioux	3.5%	2%	98%
Harrison	3.1%	37%	63%	Story	2.7%	2%	98%
Humboldt	2.2%	1%	99%	Tama	2.7%	0%	100%
Ida	2.0%	7%	93%	Webster	3.5%	2%	98%
Iowa	1.9%	16%	84%	Woodbury	3.5%	33%	67%
Jasper	2.8%	26%	74%				

<sup>¶</sup> including ridge tillage; mulch tillage; reduced tillage; conventional tillage

Cornfields in these counties annually fix about 7,873 pounds of atmospheric carbon per acre into grain, as well as into aboveground and belowground plant biomass (shoots and roots,

<sup>13</sup> Conservation Technology Information Center. National Crop Residue Management Survey.

respectively). (see Table 3) About 2,942 pounds of carbon are sequestered in corn grain, and the rest of the atmospheric carbon (about 4,931 pounds) is sequestered in corn stover and corn roots.

**Table 3 Carbon content in corn**

	Grain	Corn stover	Root
Carbon fraction (dry weight basis)	44.7% <sup>14</sup>	45.3% <sup>15</sup>	-
Carbon content	2,942 lb C/acre	2,984 lb C/acre	1,947 lb C/acre <sup>¶</sup>

<sup>¶</sup> Root C (lb C/acre) = 0.33\*(grain C + stover C)<sup>16</sup>

After harvest, biogenic carbon in corn grain (2,942 lb/acre) is transported to the wet milling facility, while biogenic carbon in corn stover and roots is either decomposed or sequestered in soil, thereby affecting the soil organic carbon (SOC) dynamics. SOC dynamics vary with climate, soil types, crop history, and crop management practices (e.g., crop rotation, tillage practice, nitrogen fertilizer application rate, etc.)<sup>17,18,19</sup>; thus we use average literature data to estimate SOC sequestration rates in these calculations. Site-specific information on the SOC dynamics is rarely available.

According to available literature<sup>17,18,20,21,22,23,24,25</sup>, plow tillage in continuous corn agriculture reduces the SOC level by about 161.5 (± 30.4) pounds of carbon per acre per year,

<sup>14</sup> M. Edgerton. Corn carbon budgets: Use of “discretionary carbon”, Biomass 2010 Conference, Arlington, VA , 2010.

<sup>15</sup> Biomass Feedstock Composition and Property Database, <http://www.afdc.energy.gov/biomass/progs/search1.cgi>.

<sup>16</sup> J.M.F. Johnson, R.R. Allmaras, D.C. Reicosky. Estimating source carbon from crop residues, roots, and rhizodeposition using the National Grain-Yield Database. *Soil Sci. Soc. Am. J.* 71:155-162, 2007.

<sup>17</sup> West TO, and Post WM (2002). Soil organic carbon sequestration rates by tillage and crop rotation: A global data analysis. *Soil Sci. Soc. Am. J.* 66:1930–1946.

<sup>18</sup> Varvel GE (2006). Soil organic carbon changes in diversified rotations of the western Corn Belt. *Soil Sci. Soc. Am. J.* 70:426–433.

<sup>19</sup> Russell AE, Laird DA, Parkin TB, Mallarino AP (2005). Impact of nitrogen fertilization and cropping system on carbon sequestration in Midwestern Mollisols. *Soil Sci Soc Am J* 69:413–422

<sup>20</sup> D.C. Reicosky, W.D. Kemper, G.W. Langdale, C.L. Douglas, Jr., P.E. Rasmussen. Soil organic matter changes resulting from tillage and biomass production. *Journal of Soil and Water Conservation.* 50(3): 253-261. 1995

<sup>21</sup> Pikul, J.L., Jr., J.M.F. Johnson, T.E. Schumacher, M. Vigil, and W.E. Riedell. 2008. Change in surface soil carbon under rotated corn in eastern South Dakota. *Soil Sci. Soc. Am. J.* 72:1738–1744.

while no-tillage practice can increase the SOC level by about 738.3 ( $\pm$  110.7) pounds of carbon per acre per year. The SOC sequestration rates for other conservation tillage practices except for no-tillage practice (i.e., ridge tillage, mulch tillage, reduced tillage and conventional tillage) are assumed to be equal to those for the plow tillage practices. *Thus our calculation is conservative; the actual carbon sequestration rate will be higher than that calculated here.* Overall, the estimated SOC sequestration rate in these counties is about 10 ( $\pm$  3.5) pounds of carbon per acre per year. In other words, continuous corn agriculture in these counties annually sequesters an average of about 10 ( $\pm$  3.5) pounds of atmospheric carbon per acre in soil.

About 5%<sup>26</sup> of biogenic carbon (147 pounds of carbon per acre) is assumed to be lost during transportation and storage. Corn grain lost during transportation and storage is probably not completely decomposed to carbon dioxide within a short timeframe. However, we use again a conservative assumption that corn grain lost during transport and storage is completely and quickly decomposed to carbon dioxide. In actual fact, not all lost grain will be decomposed quickly. Given this assumption, however, about 539 pounds of CO<sub>2</sub> per acre are released by corn grain losses during transport and storage.

The wet milling facility produces ethanol fuel and co-products (i.e., germ, fiber and gluten). The co-products are used as raw materials for corn oil (germ) and animal feed (fiber and gluten) production. Some carbon dioxide resulting from the fermentation process is sold as a co-

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<sup>22</sup> D.C. Reicosky, W.D. Kemper, G.W. Langdale, C.L. Douglas, Jr., P.E. Rasmussen. Soil organic matter changes resulting from tillage and biomass production. *Journal of Soil and Water Conservation*. 50(3): 253-261. 1995

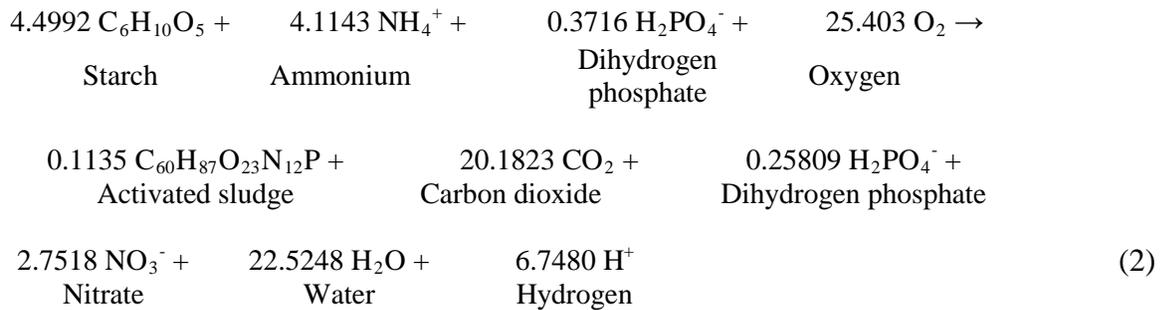
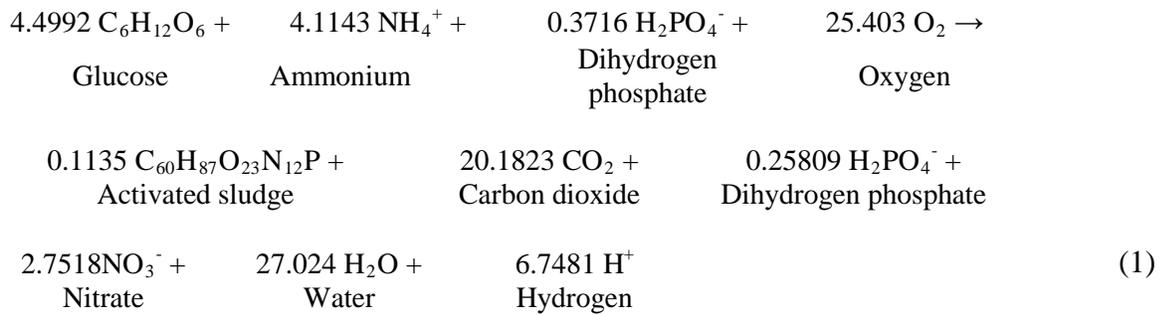
<sup>23</sup> Blanco-Canqui H. and R. Lal. 2008. No-tillage and soil-profile carbon sequestration: An on-farm assessment, *Soil Science Society of America Journal* 72, 693-701.

<sup>24</sup> E.D. Nafziger, R.E. Dunker. Soil Organic Carbon Trends Over 100 Years in the Morrow Plots. *Agron. J.* 103: 261-267, 2011.

<sup>25</sup> S. A. Khan, R.L. Mulvaney, T.R. Ellsworth, C.W. Boast. The Myth of Nitrogen Fertilization for Soil Carbon Sequestration. *J Environ Qual.* 36(6):1821-32, 2007.

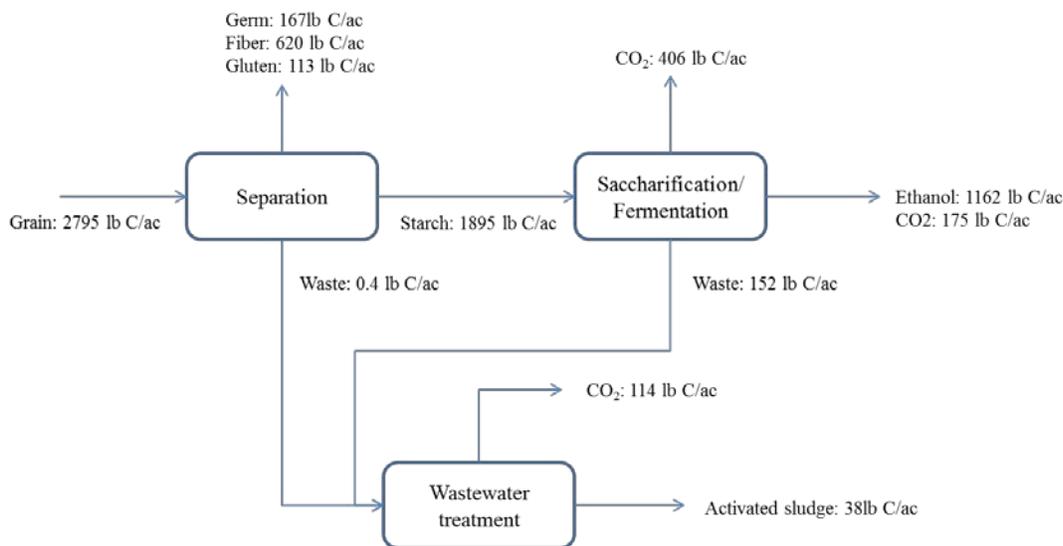
<sup>26</sup> Arbitrary value

product for various commercial purposes (carbonated drinks, industrial gases, etc.). A small fraction of biogenic carbon is treated in a wastewater treatment facility. Even though various wastewater treatment technologies might be used in the wet milling facility, for purposes of this calculation, we assume that only an activated sludge process is used. The activated sludge process for wastewater treatment is by far the oldest, least expensive and best established wastewater treatment technology. The stoichiometric equations for the activated sludge process<sup>27</sup> are given by Equations (1) and (2). One pound of biogenic carbon in the activated sludge process is converted to 0.25 pounds of biogenic carbon in activated sludge and 0.75 pounds of biogenic carbon in carbon dioxide.



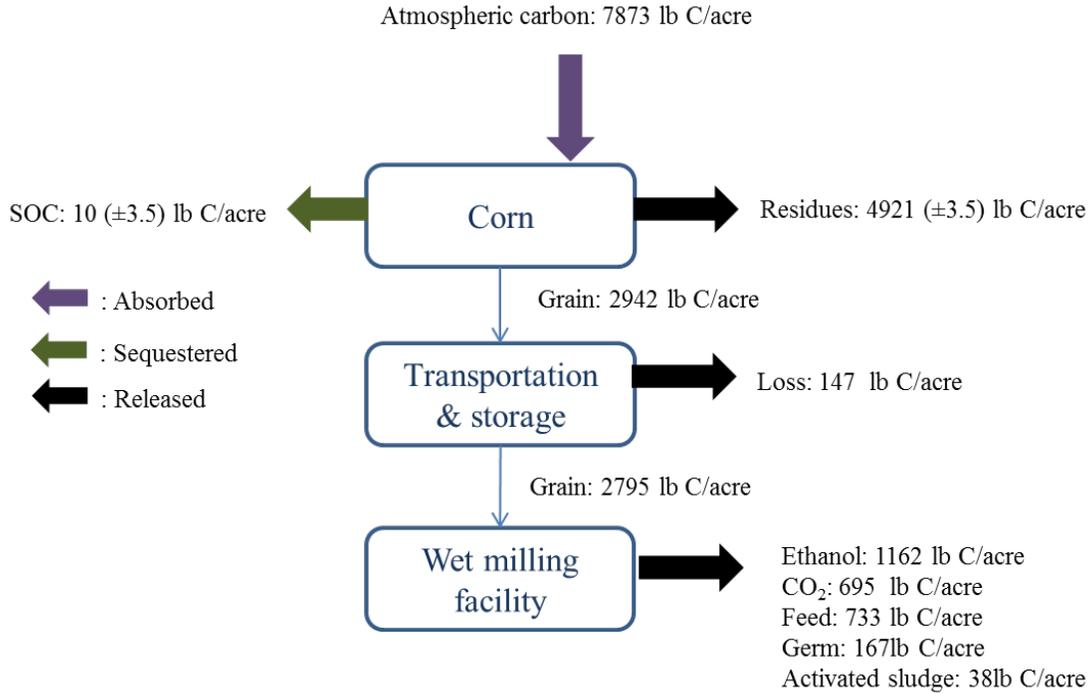
<sup>27</sup> J.H. Sherrard. Kinetics and Stoichiometry of Completely Mixed Activated Sludge. Journal of the Water Pollution Control Federation 1977, 49, 1968-1975.

The carbon balance over the wet milling facility is illustrated in Figure 2. Ethanol yield is approximately 2.58 gallons per bushel. Ethanol is eventually combusted in a vehicle and is therefore converted to carbon dioxide within a short timeframe since large inventories of ethanol fuel are not maintained in the US or elsewhere. About 733 pounds of carbon per acre are used as animal feed products: corn gluten meal and corn gluten feed, and about 167 pounds of carbon per acre are in the form of corn oil, another food and industrial product. Animal feed and corn oil are digested and converted to either carbon dioxide or methane in a short timeframe. Carbon dioxide sold by wet millers is also released to the atmosphere in a short timeframe. Activated sludge is either land applied or combusted. We assume that all the activated sludge is combusted and thereby immediately releases all of its biogenic carbon to the atmosphere. This is another conservative scenario: in fact some fraction of the carbon in the land-applied sludge would be converted to stable soil organic matter and would thereby be sequestered over a long time period.



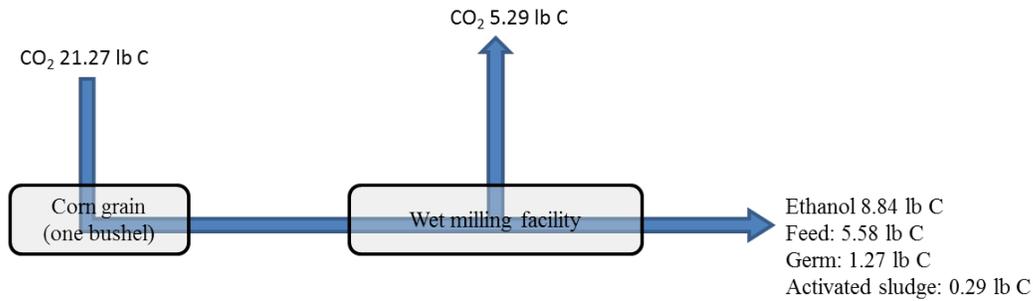
**Figure 2 Carbon balance over the wet milling facility**

The biogenic carbon balance in the corn wet milling facility for ethanol production shows that, on a net basis, about 10 ( $\pm 3.5$ ) pounds of biogenic carbon per acre are sequestered in soil, as seen in Figure 3.



**Figure 3 Biogenic carbon balance in the wet milling facility for ethanol production**

**Facility level biogenic carbon balance.** Focusing on the carbon balance at the wet mill facility level, the corn grain production system and the wet milling facility serve as a pipeline through which biogenic carbon circulates without adding new carbon atoms to the atmosphere as illustrated in Figure 4. Therefore, biogenic carbon released from the wet milling facility is carbon neutral.



**Figure 4 Facility level biogenic carbon flow for one bushel of corn grain**

**Biogenic accounting factor (BAF).** We assume that the wet milling facility requires 4 million tons of corn grain per year.

Calculating Potential Gross Emissions (**PGE**)

$$\mathbf{PGE = 4,000,000 \text{ (ton/year)} \times 0.4468 \times 44/12 \times 0.9072 = 6,553,191 \text{ t CO}_2} \quad (3)$$

Feedstock carbon lost along supply chain (**L**) = 0.05

Calculating Level of Atmospheric Reduction (**LAR**)

$$\mathbf{LAR = 4,200,000 \text{ Tons per year} / 4,200,000 \text{ Tons per year} = 1} \quad (4)$$

Calculating Carbon (as carbon dioxide) in Products (**PRODC**)

$$\begin{aligned} \text{Carbon content of ethanol} &= 4,000,000 \text{ (ton/year)} \times 2.584 \text{ (gal/bushel)} \times (2000/56) \times 0.003291 \text{ (ton/gal)} \\ &\times 0.5214 \times 44/12 \times 0.9072 = 2,107,144 \text{ t CO}_2 \end{aligned} \quad (5)$$

$$\begin{aligned} \text{Carbon content of co-products (germ, fiber, gluten)} &= 4,000,000 \text{ (ton/year)} \times 0.27 \text{ (ton/ ton)} \times 0.452 \\ &\times 44/12 \times 0.9072 = 1,632,571 \text{ t CO}_2 \end{aligned} \quad (6)$$

$$\begin{aligned} \text{Carbon content of CO}_2 \text{ sold} &= 4,000,000 \text{ (ton/year)} \times 0.087 \text{ (ton/ ton)} \times 0.273 \times 44/12 \times 0.9072 \\ &= 316,930 \text{ t CO}_2 \end{aligned} \quad (7)$$

$$\text{PRODC} = (2,107,144 + 1,632,571 + 316,930)/6,553,191 = 0.62 \quad (8)$$

Calculating Sequestered Fraction (SEQP)

$$\begin{aligned} \text{SEQP (activated sludge)} &= 4,000,000 \text{ (ton/year)} \times 0.0052 \text{ (ton Carbon/ ton)} \times 44/12 \\ &\times 0.9072 / 6,553,191 = 0.01 \end{aligned} \quad (9)$$

Calculating Total Net Change in Site Emissions (SITE\_TNC)

$$\text{ACRES} = 4,200,000 \text{ (ton/year)} / 3.87 \text{ (ton/acre)} = 1,084,286 \text{ acre} \quad (10)$$

Note that feedstock losses in the supply chain are included in the calculation at this point in order to supply the facility with 4,000,000 tons per year of corn grain.

$$\begin{aligned} \text{SITE\_TNC} &= -10 (\pm 3.5) \text{ (lb C/acre)} / 2000 \times 44/12 \times 0.9072 \times 1,084,286 \text{ (acre)} \\ &= -18,034 (\pm 6,312) \text{ t CO}_2 \end{aligned} \quad (11)$$

Assuming no leakage

Calculating Net Biogenic Emissions (NBE)

$$\text{PGE} \times (1 + L) \times (1 - \text{LAR}) \times (1 - \text{PRODC}) = 0 \quad (12)$$

$$\text{PGE} \times \text{SEQP} = 69,599 \text{ t CO}_2 \quad (13)$$

$$\text{SITE\_TNC} \times (1 - \text{PRODC}) = -6,870 (\pm 2,405) \text{ t CO}_2 \quad (14)$$

$$\text{NBE} = -69,599 - 6,870 (\pm 2,405) = -76,469 (\pm 2,405) \text{ t CO}_2 \quad (15)$$

Calculating Biogenic Accounting Factor (BAF)

$$\text{BAF} = -76,469 (\pm 2,405)/6,553,191 = -0.012 (\pm 0.0004) \quad (16)$$

## A2. Fermentation in a dry milling facility producing corn ethanol

This example illustrates the biogenic carbon cycle in a corn dry milling facility producing corn ethanol and distillers grains, an animal feed. This facility also uses corn grain from the same counties as used in the wet milling facility example. Unlike the wet milling facility case, no commercial information from actual, specific businesses is available at this time. The calculations in this example are based on literature information. As an overall system, corn ethanol production in a dry milling facility also sequesters on a net basis about 10 ( $\pm 3.5$ ) pounds of biogenic carbon per acre. BAF for corn dry milling facility is  $-0.001$  ( $\pm 0.0004$ ).

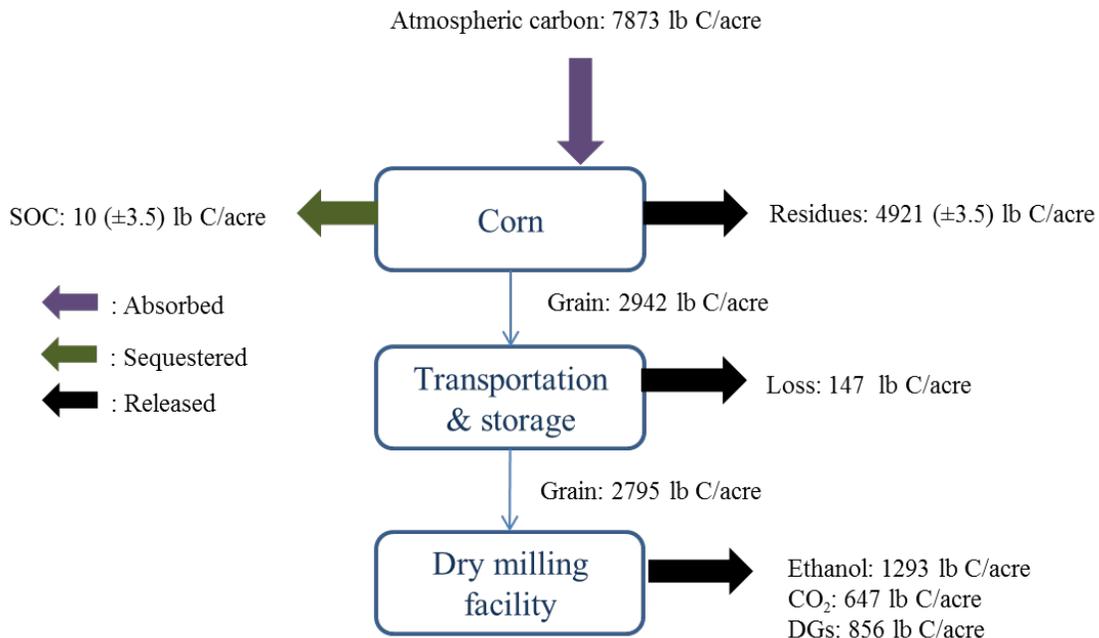
**Life cycle biogenic carbon balance.** The biogenic carbon balance from corn production to transportation and storage at the dry milling facility is identical to that for the wet milling facility considered previously. The dry milling facility does not have a separation process for fiber, gluten and germ. Starch is converted to glucose with no biogenic carbon loss in the saccharification process. The mass fraction of starch in corn grain is 73.4%<sup>28</sup> (based on dry weight) and thus the biogenic carbon in corn starch is equal to 2,041 pounds of carbon per acre. At a conversion rate of starch to ethanol of 96%, about 1,959 pounds of carbon in starch (per acre basis) are converted to carbon in glucose. About 82 pounds of carbon per acre in starch are not converted.

In the fermentation process, one mole of glucose is converted to 2 moles of ethanol and 2 moles of carbon dioxide. At a conversion rate of 99%, about 1,940 pounds of carbon in glucose give rise to 1,293 pounds of carbon in ethanol and 547 pounds of carbon in carbon dioxide, while

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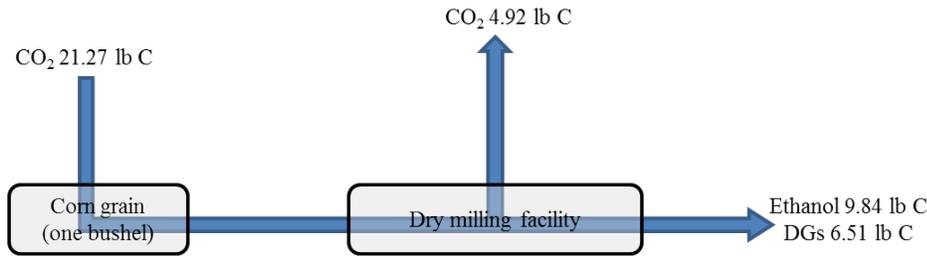
<sup>28</sup> P. J. White, L.A. Johnson (eds). Corn: chemistry and technology. St. Paul, MN: American Association of Cereal Chemists, 2003.

about 20 pounds of carbon in glucose are either unreacted or are fixed as organic carbon in the bodies of the microorganisms that produce the ethanol. The remaining unfermented starch, glucose, yeast, and other products (e.g., protein, germ, etc.), representing a total of 856 pounds of carbon, are combined into an animal feed product known as Distillers Grains with Solubles (DGS). The ethanol yield is approximately 2.80 gallon per bushel. Ethanol is eventually combusted in a vehicle and converted to carbon dioxide in a short timeframe. That carbon dioxide is included in this LCA-type analysis. Distillers grains are fed to animals and are thereby also digested and converted to either carbon dioxide or methane in a short time frame. We assume that no carbon dioxide is sold as a co-product from the dry milling facility. The biogenic carbon balance in a dry milling facility also shows on a net basis that about 10 ( $\pm 3.5$ ) pounds of biogenic carbon per acre are sequestered in soil, as seen in Figure 5.



**Figure 5 Biogenic carbon balance in the dry milling facility for ethanol production**

**Facility level biogenic balance.** Like the biogenic carbon cycle in the wet milling facility, biogenic carbon released from the illustrative dry milling facility is carbon neutral as illustrated in Figure 7. As explained previously, by “carbon neutral” we mean that this carbon from the dry milling plant neither adds to nor diminishes from atmospheric stocks of carbon (present as carbon dioxide).



**Figure 6 Facility level biogenic carbon flow for one bushel of corn grain**

**Biogenic accounting factor (BAF).** We assume that the dry milling facility requires 4 million tons of corn grain per year.

Calculating Potential Gross Emissions (**PGE**)

$$\mathbf{PGE = 4,000,000 \text{ (ton/year)} \times 0.4468 \times 44/12 \times 0.9072 = 6,553,191 \text{ t CO}_2} \quad (17)$$

Feedstock carbon lost along supply chain (**L**) = 0.05

Calculating Level of Atmospheric Reduction (**LAR**)

$$\mathbf{LAR = 4,200,000 \text{ Tons per year} / 4,200,000 \text{ Tons per year} = 1} \quad (18)$$

Calculating Carbon (as carbon dioxide) in Products (**PRODC**)

$$\text{Carbon content of ethanol} = 2,337,752 \text{ t CO}_2 \quad (19)$$

$$\text{Carbon content of co-products (DG)} = 1,546,669 \text{ t CO}_2 \quad (20)$$

$$\text{PRODC} = (2,337,752 + 1,546,669)/6,553,191 = 0.59 \quad (21)$$

Calculating Sequestered Fraction (**SEQP**)

$$\text{SEQP} = 0 \quad (22)$$

Calculating Total Net Change in Site Emissions (**SITE\_TNC**)

$$\text{ACRES} = 4,200,000 \text{ (ton/year)} / 3.87 \text{ (ton/acre)} = 1,084,286 \text{ acre} \quad (23)$$

Note that feedstock losses in the supply chain are included in the calculation at this point in order to supply the facility with 4,000,000 tons per year of corn grain.

$$\begin{aligned} \text{SITE\_TNC} &= -10 (\pm 3.5) \text{ (lb C/acre)} / 2000 \times 44/12 \times 0.9072 \times 1,084,286 \text{ (acre)} \\ &= -18,034 (\pm 6,312) \text{ t CO}_2 \end{aligned} \quad (24)$$

Assuming no leakage

Calculating Net Biogenic Emissions (**NBE**)

$$\text{PGE} \times (1 + L) \times (1 - \text{LAR}) \times (1 - \text{PRODC}) = 0 \quad (25)$$

$$\text{PGE} \times \text{SEQP} = 0 \text{ t CO}_2 \quad (26)$$

$$\text{SITE\_TNC} \times (1 - \text{PRODC}) = -7,344 (\pm 2,570) \text{ t CO}_2 \quad (27)$$

$$\text{NBE} = -7,344 (\pm 2,570) \text{ t CO}_2 \quad (28)$$

Calculating Biogenic Accounting Factor (**BAF**)

$$\text{BAF} = -7,344 (\pm 2,570)/6,553,191 = -0.001(\pm 0.0004) \quad (29)$$

### A3. Corn stover combustion in a boiler facility

This example shows the biogenic carbon cycle for corn stover combustion in an industrial boiler facility. A life cycle biogenic carbon balance for corn stover combustion shows that about 5 pounds of biogenic carbon per acre are fixed. BAF for corn stover combustion facility is -0.008. The overall process of corn stover production and combustion therefore sequesters some atmospheric carbon on a net basis. In practice, however, more atmospheric carbon would be sequestered than this, since our calculations are conservative, as described above.

**Life cycle biogenic carbon balance.** An average cornfield in the U.S. can fix about 7,023 pounds of atmospheric carbon per acre per year into grain, and aboveground and belowground biomass. (see Table 3) Note that the US average corn yield in 2012 was 123.4 bushel/acre. About 2,662 pounds of carbon per acre are fixed in corn stover.

Excessive removal of corn stover from corn fields would increase the risk of soil erosion and would tend to decrease soil organic carbon (SOC) levels. Wilhelm et al. (2007)<sup>29</sup> estimate about 2.34 – 5.68 tons of dry corn stover per acre are needed to maintain the SOC levels. The Renewable Fuel Standard Program (RFS2) gives allowable corn stover removal fractions depending on the tillage practices employed - 50% can be removed under no tillage, 35% under conservation tillage and 0% under conventional tillage practices. Recently, Follett et al. (2012)<sup>30</sup> show that about 50% corn stover removal in no-tillage practices would increase the SOC levels by about 493 pounds of carbon per acre per year at a soil depth of 0 - 30 cm or 1,383 pounds of carbon per acre per year at soil depths of 0 - 150 cm.

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<sup>29</sup> W.W. Wilhelm et al. Corn Stover to Sustain Soil Organic Carbon Further Constrains Biomass Supply. *Agron. J.* 2007, 99, 1665–1667.

<sup>30</sup> R.F. Follett et al. Soil Carbon Sequestration by Switchgrass and No-Till Maize Grown for Bioenergy. *Bioenerg. Res.* 2012, 5, 866–875.

We assume that only conservation tillage practices are followed and therefore that only 35% of residue is removed, a conservative assumption since some no-till will certainly be done. About 1,190 pounds of dry corn stover per acre (539 pounds of biogenic carbon per acre) is removed in conservation tillage practices because about 4,684 pounds of dry corn stover per acre is needed under conservation tillage practices to maintain the SOC levels. Therefore, corn stover removal in this example does not affect the SOC levels. As in the previous examples for corn grain, we assume that 5% of biogenic carbon is lost during transportation and storage. Thus about 27 pounds of biogenic carbon per acre (as corn stover) are therefore released during transportation and storage.

The composition of corn stover is needed to complete the stoichiometry of corn stover combustion in a boiler facility. These data and combustion reactions are summarized in Table 4 and Table 5. According to the NREL Aspen Plus model<sup>31</sup>, about 99% of each component is oxidized or decomposed. Thus about 507 pounds of biogenic carbon per acre are converted to carbon dioxide and released. The rest is converted to biochar or ash; this is an amount equal to about 5 pounds of carbon per acre. The mass balance over a boiler facility is illustrated in Figure 7.

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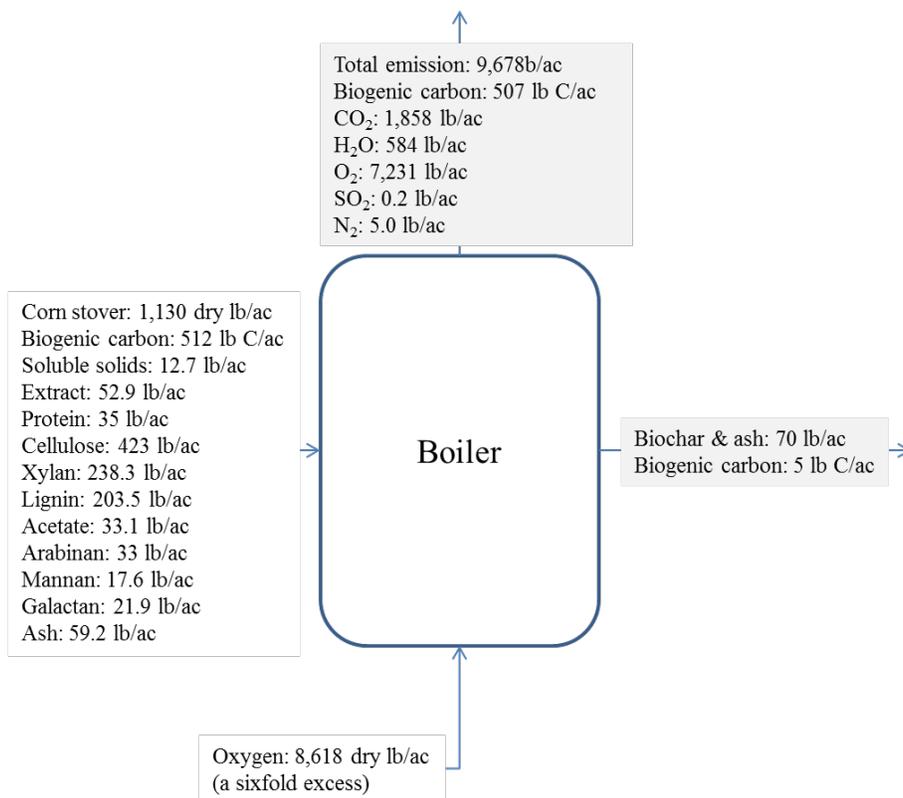
<sup>31</sup> A. Aden, M. Ruth, K. Ibsen et al. Lignocellulosic Biomass to Ethanol Process Design and Economics Utilizing Co-Current Dilute Acid Prehydrolysis and Enzymatic Hydrolysis for Corn Stover. Report No. NREL/TP-510-32438. Golden, CO: National Renewable Energy Laboratory, 2002.

**Table 4 Composition of corn stover**

	Fraction (%)	Molecular weight (lb/mole)	Carbon fraction (%)
Soluble solids	1.0%	98.3	12%
Extract	4.0%	98.3	12%
Protein	2.6%	98.3	12%
Water	15.0%	18.0	0%
Cellulos	31.8%	162.1	44%
Xylan	17.9%	132.1	45%
Lignin	15.3%	154.9	78%
Acetate	2.5%	60.1	40%
Arabinan	2.5%	132.1	45%
Mannan	1.3%	162.1	44%
Galactan	1.7%	162.1	44%
Ash	4.4%	56.1	0%

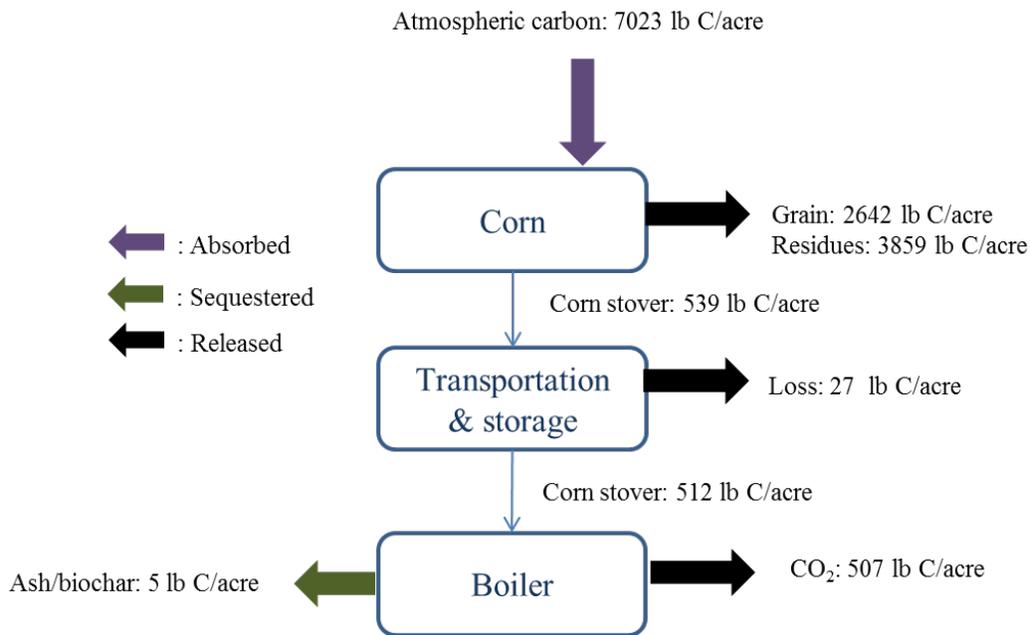
**Table 5 Oxidation reactions in a boiler facility**

Cellulose + 6 O <sub>2</sub> → 5 H <sub>2</sub> O + 6 CO <sub>2</sub>
Xylan + 5 O <sub>2</sub> → 4 H <sub>2</sub> O + 5 CO <sub>2</sub>
Arabinan + 5 O <sub>2</sub> → 4 H <sub>2</sub> O + 5 CO <sub>2</sub>
Mannan + 6 O <sub>2</sub> → 5 H <sub>2</sub> O + 6 CO <sub>2</sub>
Lignin + 12.825 O <sub>2</sub> → 6.95 H <sub>2</sub> O + 10 CO <sub>2</sub>
Galactan + 6 O <sub>2</sub> → 5 H <sub>2</sub> O + 6 CO <sub>2</sub>
Acetate + 2 O <sub>2</sub> → 2 H <sub>2</sub> O + 2 CO <sub>2</sub>
Extract → 0.05487023 H <sub>2</sub> O + 0.18311555 N <sub>2</sub> + CO <sub>2</sub> + 1.49949807 O <sub>2</sub> + 0.0027821 SO <sub>2</sub>
Protein → 0.05487023 H <sub>2</sub> O + 0.18311555 N <sub>2</sub> + CO <sub>2</sub> + 1.49949807 O <sub>2</sub> + 0.0027821 SO <sub>2</sub>
Soluble solids → 0.05487023 H <sub>2</sub> O + 0.18311555 N <sub>2</sub> + CO <sub>2</sub> + 1.49949807 O <sub>2</sub> + 0.0027821 SO <sub>2</sub>



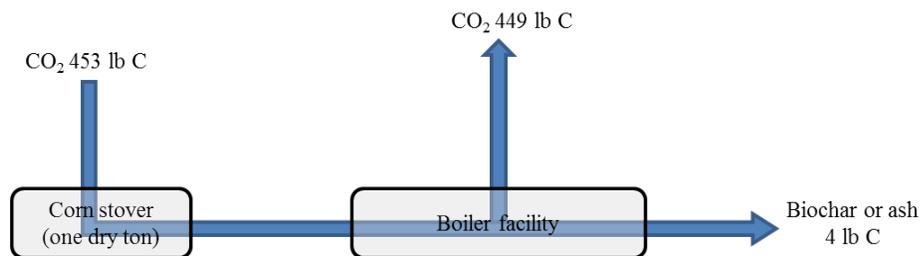
**Figure 7 Mass balance in the boiler**

The biogenic carbon balance in the corn stover combustion shows that about 5 pounds of biogenic carbon per acre are sequestered in soil, on a net basis, as seen in Figure 8.



**Figure 8 Biogenic carbon cycle in corn stover combustion**

**Facility level biogenic balance.** Biogenic carbon released from the boiler facility is carbon neutral as illustrated in Figure 9.



**Figure 9 Facility level biogenic carbon flow for one ton of dry corn stover**

**Biogenic accounting factor (BAF).** We assume that a boiler facility combusts 1 million tons of dry corn stover per year.

Calculating Potential Gross Emissions (**PGE**)

$$\text{PGE} = 1,000,000 \text{ (ton/year)} \times 0.4532 \times 44/12 \times 0.9072 = 1,661,730 \text{ t CO}_2 \quad (30)$$

Feedstock carbon lost along supply chain (**L**) = 0.05

Calculating Level of Atmospheric Reduction (**LAR**)

$$\text{LAR} = 1 \quad (31)$$

Calculating Carbon (as carbon dioxide) in Products (**PRODC**)

$$\text{PRODC} = 0 \quad (32)$$

Calculating Sequestered Fraction (**SEQP**)

$$\begin{aligned} \text{SEQP (biochar)} &= 1,000,000 \text{ (ton/year)} \times 0.0045 \text{ (ton Carbon/ ton)} \times 44/12 \\ &\quad \times 0.9072 / 1,661,730 = 0.01 \end{aligned} \quad (33)$$

Calculating Total Net Change in Site Emissions (**SITE\_TNC**)

$$\text{SITE\_TNC} = 0 \quad (34)$$

Assuming no leakage

Calculating Net Biogenic Emissions (**NBE**)

$$\text{PGE} \times (1 + \text{L}) \times (1 - \text{LAR}) \times (1 - \text{PRODC}) = 0 \quad (35)$$

$$\text{PGE} \times \text{SEQP} = 15,078 \text{ t CO}_2 \quad (36)$$

$$\text{SITE\_TNC} \times (1 - \text{PRODC}) = 0 \quad (37)$$

$$\text{NBE} = - 15,078 \text{ t CO}_2 \quad (38)$$

Calculating Biogenic Accounting Factor (**BAF**)

$$\text{BAF} = -15,078/1,661,730 = -0.01 \quad (39)$$

#### A4. Biological wastewater treatment facility

This example illustrates the biogenic carbon cycle in a wastewater treatment facility such as a publicly owned treatment works (POTW) particularly for the activated sludge process, including sludge (biosolids) disposal processes. Due to the myriad origins of wastewater, especially sewage, a life cycle biogenic carbon balance is not estimated. However, it is assumed here that the biogenic carbon in the wastewater all originated in plant material. A life cycle biogenic carbon balance for an aerobic treatment shows that about 0.05 pounds of biogenic carbon per pound of biogenic carbon in wastewater are sequestered. BAF for the aerobic treatment facility is -0.05.

**Overall carbon flow.** The biogenic carbon balance in the aerobic treatment is estimated based on Equations (1) and (2). To reflect the current situation for the sludge disposal, we use the 2004 data, in which about 55% of biosolids were used in land application, while 45% were disposed (landfill: 30% and incineration: 15%)<sup>32</sup>. The biogenic carbon balances in the sludge disposal stages are based on the Biosolids Emissions Assessment Model (BEAM)<sup>33</sup> and summarized in Table 6.

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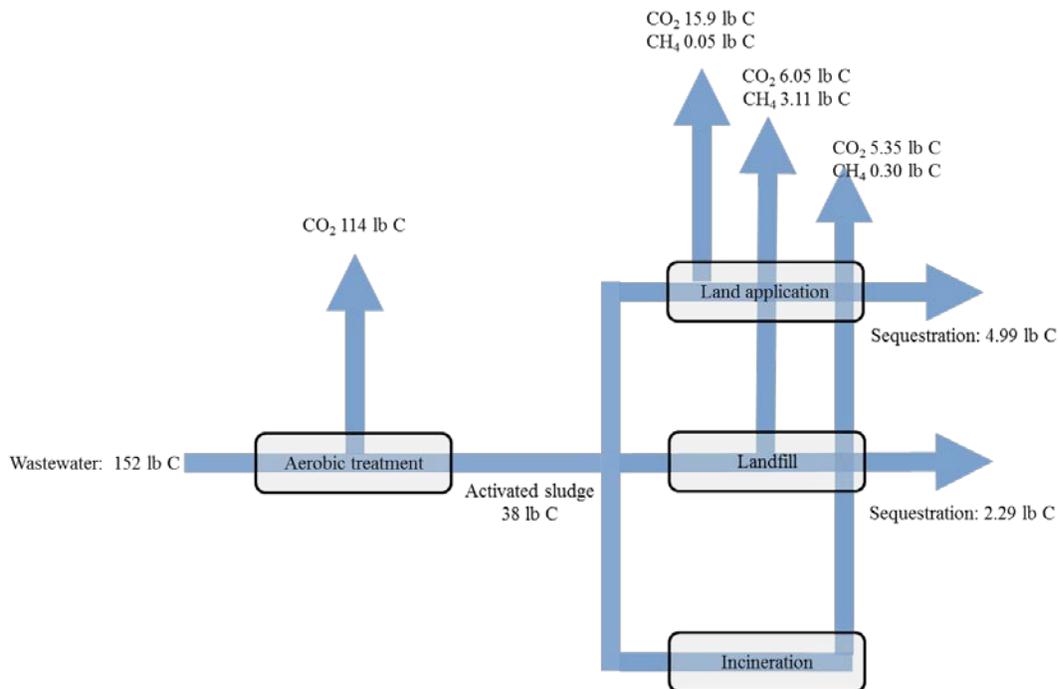
<sup>32</sup> North East Biosolids and Residuals Association, National Biosolids Regulation, Quality, End Use, and Disposal Survey, 2007

<sup>33</sup> Sally Brown, Ned Beecher, Andrew Carpenter, Calculator tool for determining greenhouse gas emissions for biosolids processing and end use. Environmental Science & Technology 2010; 44(24):9509-15.

**Table 6 biogenic carbon balances in the sludge disposal**

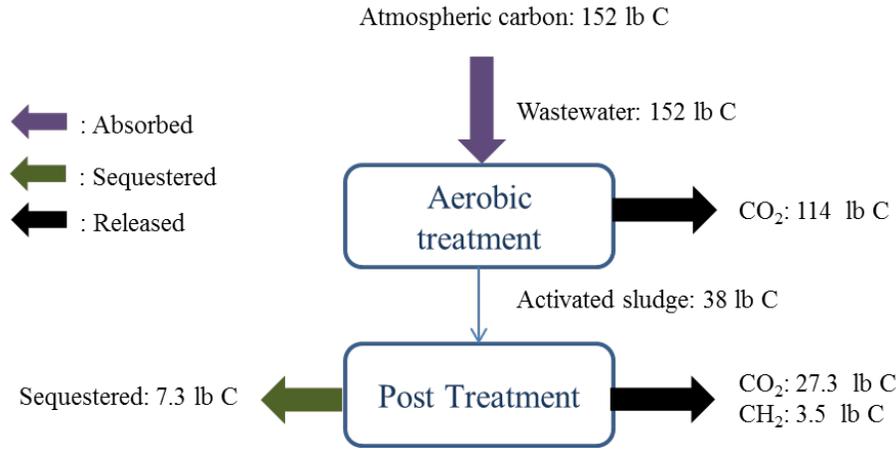
	Land application	Landfill Disposal	Combustion (incineration, thermal oxidation)
Biogenic carbon Sequestration	24%	20%	0%
Biogenic carbon released as CH <sub>4</sub>	0.2%	27%	5%
Biogenic carbon released as CO <sub>2</sub>	76%	53%	95%

The results show that about 75% of total biogenic carbon in the wastewater stream are released as CO<sub>2</sub> in the aerobic treatment, and about 20 % of total biogenic carbons are released as CO<sub>2</sub> (18%) and CH<sub>4</sub> (2%) in the sludge disposal stages. About 5% of total biogenic carbon in the wastewater stream is sequestered in agricultural soil and landfill sites. The overall balance is illustrated in Figure 10.



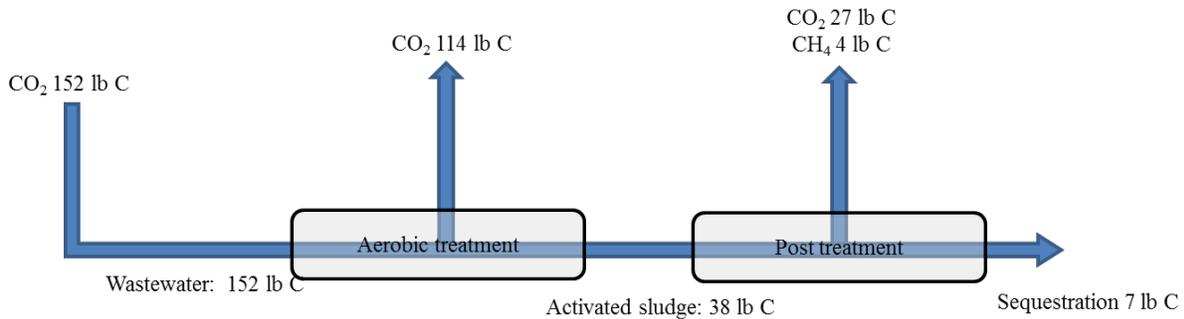
**Figure 10 Overall carbon flow for aerobic wastewater treatment**

The biogenic carbon balance in an aerobic waste treatment also shows on a net basis that about 0.05 pounds of biogenic carbon per pound of biogenic carbon in wastewater are sequestered as seen in Figure 11.



**Figure 11 Biogenic carbon balance in the aerobic wastewater treatment**

**Facility level biogenic balance.** Like the previous examples, the aerobic wastewater treatment process does not increase the atmospheric carbon concentration as seen Figure 12.



**Figure 12 Facility level biogenic carbon flow for aerobic wastewater treatment**

**Biogenic accounting factor (BAF).** We assume that the aerobic wastewater treatment facility treat wastewater containing 1 million ton of biogenic carbon.

Calculating Potential Gross Emissions (**PGE**)

$$\mathbf{PGE = 1,000,000 \text{ (ton/year)} \times 44/12 \times 0.9072 = 3,666,667 \text{ t CO}_2} \quad (40)$$

Feedstock carbon lost along supply chain (**L**) = 0

Calculating Level of Atmospheric Reduction (**LAR**)

$$\mathbf{LAR = 1} \quad (41)$$

Calculating Sequestered Fraction (**SEQP**)

$$\mathbf{SEQP = 1,000,000 \text{ (ton/year)} \times 7.3/ 152 \text{ (lb C/ lb C)} \times 44/12 \times} \\ \mathbf{0.9072 / 3,666,667 = 0.04} \quad (42)$$

Calculating Total Net Change in Site Emissions (**SITE\_TNC**)

$$\mathbf{SITE\_TNC = 0} \quad (43)$$

Assuming no leakage

Calculating Net Biogenic Emissions (**NBE**)

$$\mathbf{PGE \times (1 + L) \times (1 - LAR) \times (1 - PRODC) = 0} \quad (44)$$

$$\mathbf{PGE \times SEQP = 0.04 \times 3,666,667 = 159,294 \text{ t CO}_2} \quad (45)$$

$$\mathbf{NBE = - 159,294 \text{ t CO}_2} \quad (46)$$

Calculating Biogenic Accounting Factor (**BAF**)

$$\mathbf{BAF = - 159,294/3,666,667 = -0.05} \quad (47)$$

## Appendix B. Curriculum Vitae

BRUCE E. DALE

Ph.D., Professor of Chemical Engineering, Michigan State University

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### **EDUCATION AND TRAINING:**

1979 Ph.D. Chemical Engineering, Purdue University, West Lafayette, Indiana

1976 M.S. Chemical Engineering, University of Arizona, Tucson

1974 B.S. Chemical Engineering, University of Arizona, Tucson (magna cum laude)

### **PROFESSIONAL EXPERIENCE & HONORS**

Professor, Dept. of Chemical Engr. & Materials Science, Michigan State Univ., 2001-present

Professor and Chair, Dept. of Chemical Engineering, Michigan State University, 1996 – 2001

Professor, Chemical Engineering & Agricultural Engineering, Texas A&M Univ., 1991 – 1995

Director, Food Protein Research and Development Center, Texas A&M Univ., 1991 – 1993

Director, Engineering Biosciences Research Center, Texas A&M Univ., 1990-1995

Associate Professor, Chemical and Agricultural Engineering, Texas A&M Univ., 1988 – 1991

Professor, Chemical Engineering, Colorado State Univ., 1988 – 1988

Associate Prof., Chemical Engineering, Colorado State Univ., 1983– 1988

Assistant Professor, Chemical Engineering, Colorado State Univ., 1979 – 1983

Halliburton Outstanding Young Faculty Award (1982)

Abell Young Faculty Research Award (1984)

Colorado State University Research Foundation Researcher of the Year (1986)

Engineering Dean's Council Award (1987)

Editorial Board, Biotechnology Progress (1989-present)

Editorial Board, Biotechnology and Bioengineering (2002-present)

Editor, Bioresource Technology (1991-1996)

Editor in Chief, Biofuels, Bioproducts & Biorefineries (2007-present)

Co-Chair, National Research Council Committee on Biobased Industrial Products (1994-2000)

Charles D. Scott Award (1996)

Sterling Hendricks Award (2007)

Distinguished University Faculty Award (2008)

Fellow of the American Institute of Chemical Engineers (2011)

Fuel Ethanol Workshop Award of Technical Excellence (2011)

Outstanding Chemical Engineering Alumnus- Purdue University (2012)

### **SYNERGISTIC ACTIVITIES**

- Leading member of the CAFI (Consortium for Applied Fundamentals and Innovation) that worked to rigorously compare and develop advanced biomass pretreatments
- Leader of the Biomass Processing area of the Great Lakes Bioenergy Center funded by the U. S. Dept. of Energy (\$25 million per year for 5 years), participating the Sustainability area of this Center also.
- Active collaborations with industry and agricultural economics and animal science faculty to explore viable process designs for distributed or regional biomass processing.
- Editor in Chief of the journal Biofuels, Bioproducts and Biorefining. The journal emphasizes innovation for a sustainable economy and has achieved a high (5.21) impact factor in only 6 years.

### **PUBLICATIONS 2009-2012**

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## SEUNGDO KIM

Associate Professor, Department of Chemical Engineering & Materials Science, Michigan State  
University (MSU)

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### EDUCATION AND TRAINING:

1984 B.S., Hanyang University, Seoul, KOREA, Chemical Engineering

1986 M.S., Hanyang University, Seoul, KOREA, Chemical Engineering

1993 Ph.D., Louisiana State University, Chemical Engineering

### PROFESSIONAL EXPERIENCE:

2009 – Present Associate Professor, Michigan State University

2005 – 2009 Visiting Associate Professor, Michigan State University

2001 – 2005 Visiting Research Associate, Michigan State University

1998 – 2001 Postdoc/Research Associate, North Carolina State University

1994 – 1998 Project Manager, Samsung Electronics Co., Ltd., Korea

### SELECTED PUBLICATIONS:

- Kim, S., Dale, B. E and Ong, R. C. An alternative approach to indirect land use change: Allocating greenhouse gas effects among different uses of land, *Biomass and Bioenergy*, 46, 447-452, 2012.
- Kim, S. and Dale, B. E. Indirect land use change for biofuels: Testing predictions and improving analytical methodologies, *Biomass and Bioenergy*, 35(7), 3235-3240, 2011.
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**SYNERGISTIC ACTIVITIES:**

- **Areas of Expertise:** Over 17-years of experience on environmental life cycle assessment for various types of products: home appliances, electronics, chemicals, pharmaceuticals, and biobased products. Most current projects have focused on life cycle assessment studies for biofuels, biopolymers, chemicals and agricultural productions.
- **Awards and Honors:** Submission Editor of International Journal of Life Cycle Assessment