# Lifecycle GHG Emissions from Abengoa Bioenergy Biomass of Kansas, LLC Hugoton Cellulosic Ethanol Plant

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**Lifecycle GHG Emissions from Abengoa Hugoton Cellulosic Ethanol Plant**

## 1.0 Introduction

The Abengoa Bioenergy Biomass of Kansas ("ABBK") Plant in Hugoton, Kansas (henceforth referred to as ABBK) is a cellulosic ethanol plant that will come on-line in 2014. [redacted] Ethanol is produced via a fermentation process. Energy for the plant is co-generated via combustion of unrecoverable biomass residues and process biomass waste products. During start-up/shutdown sequences, natural gas energy is used to supplement the plant. Excess electricity is exported to the local grid.

[redacted] The expected mix of biomass into the plant is [redacted] corn stover and [redacted] wheat straw. The CI for each feedstock is calculated separately. CIs have been separately estimated at a nominal yield of [redacted] gal/bdt corn stover and [redacted] gal/bdt wheat straw for the two different feedstocks (see footnote 1).

The California GREET model, CA_GREET2.0_v220, henceforth referred to as CA_GR220, is configured for corn stover and wheat straw to ethanol.[2] The miscanthus array provides a calculation framework for the ABBK wheat straw pathway.

This report is divided into the following sections:

- Feedstocks, Transport, and Land Use
- Process Flow
- Energy Balance
- ABBK Plant
- GREET Modifications
- Results

[1] Some unrecoverable biomass fines from grinding etc., is used directly as a process fuel, so the projected yield of biomass going to ethanol production is [redacted] gal/bdt corn stover and [redacted] gal/bdt wheat straw. The yields have been rounded to the nearest whole number for reporting purposes.

[2] We used the CA_GREET2 model available in December 2014. The model is expected to be adopted by ARB in February 2015.

## 2.0 Feedstocks, Transport, and Land Use

Two feedstocks will be used for ABBK – corn stover and wheat straw.

### 2.1 Corn Stover

The corn stover will be baled and picked up from the fields after the corn harvest, then transported to ABBK. Abengoa anticipates that approximately [redacted] of the corn stover left on the field will be utilized. See Appendix 3 for more details. [redacted]

Corn stover is a residue of the corn plant left in the field after corn harvest and is made up of the plant's stalks, leaves, and cob. Collection steps include windrowing, baling, stacking and loading on transport trucks. [redacted]

CA_GR220 currently includes calculations for farming, agriculture chemical, and transport emissions for corn stover. GREET's agriculture chemical emissions for corn stover assume some replacement of nutrients (nitrogen, etc.) to the field to compensate for the removal of some corn stover.

- GREET calculates make up fertilizer based on the nutrient content of the removed crop. The N content of corn stover and the fertilizer mix for corn stover were adjusted to reflect actual data. The CA_GR220 default for N content in corn stover is 7000 g/BD ton. This includes the additional fertilizer applied that is volatilized on application.
- GREET assumes that 2% of the residue is lost in transit. Abengoa has not experienced this level of product loss. [redacted]
- GREET estimates dry matter losses in storage. The analysis assumes the [redacted] loss factor for Large Square Bales (LSB). See Appendix 1 for more details.

---

[redacted]

- [redacted]

**Table 2**. Revised N fertilizer inputs for Midwestern production.

[redacted]

2.2 Wheat Straw

Wheat Straw ethanol is not included in GREET, we have modified the miscanthus array to calculate the wheat straw ethanol pathway. This array is populated with data and assumptions from ABBK and GREET as outlined here.

The wheat straw will also be baled and transported to ABBK. [redacted] We are modeling farming emissions for wheat straw as the same emissions as used for corn stover, since emissions from material pickup and baling after harvesting should be very similar to corn stover. See Appendix 1 for more details.

- GREET calculates make up fertilizer based on the nutrient content of the removed crop. The N content of wheat straw and the fertilizer mix were adjusted to reflect actual data. [redacted] An additional 10% N is added to account for volatilization on application bringing the total replacement N fertilizer to [redacted] g/BD ton.

[redacted]

**Figure 2.** Wheat Straw Nitrogen wt. % based on data provided by Abengoa.

• GREET assumes that 2% of the residue is lost in transit. Abengoa has not experienced this level of product loss. [redacted]

2.3 Farming Inputs

Research conducted for GREET on nutrient removal evaluated the nutrients supplied by the corn stover, and how much would be lost if 50% corn stover were removed. The nutrients replace what was lost through removal of corn stover.

The nitrogen, phosphorous, and potassium in corn stover assumed in GREET are shown in Table 3. We also show the nutrients in wheat straw, based USDA inputs for nutrient content. For more information, see Appendix 2.

**Table 3. Nutrients in Corn Stover and Wheat Straw (g/ton)**

[redacted]

To model nutrients added for wheat straw removal, we input the data in Table 3 for wheat straw into CA_GR220 in the appropriate cells. See appendix 6 for modifications to the CA_GR220 model.

2.4 Indirect Land Use for Feedstocks

Corn stover and wheat straw are crop residues. Removal of these crop residues does not change the supply and demand of crops and therefore the indirect land use emissions are zero.

2.5 $N_2O$ emissions

[redacted]

2.6 Feedstock Transport Distances

The CA_GRV220 default transport distances of 52 miles for corn stover and 36 miles for wheat straw have been applied. Feedstock transport distance will vary with crop yields and other factors. The GREET default covers the range of expected outcomes.

[redacted]

[redacted]

**Figure 3.** ABBK feedstock locations and distances.

[redacted]

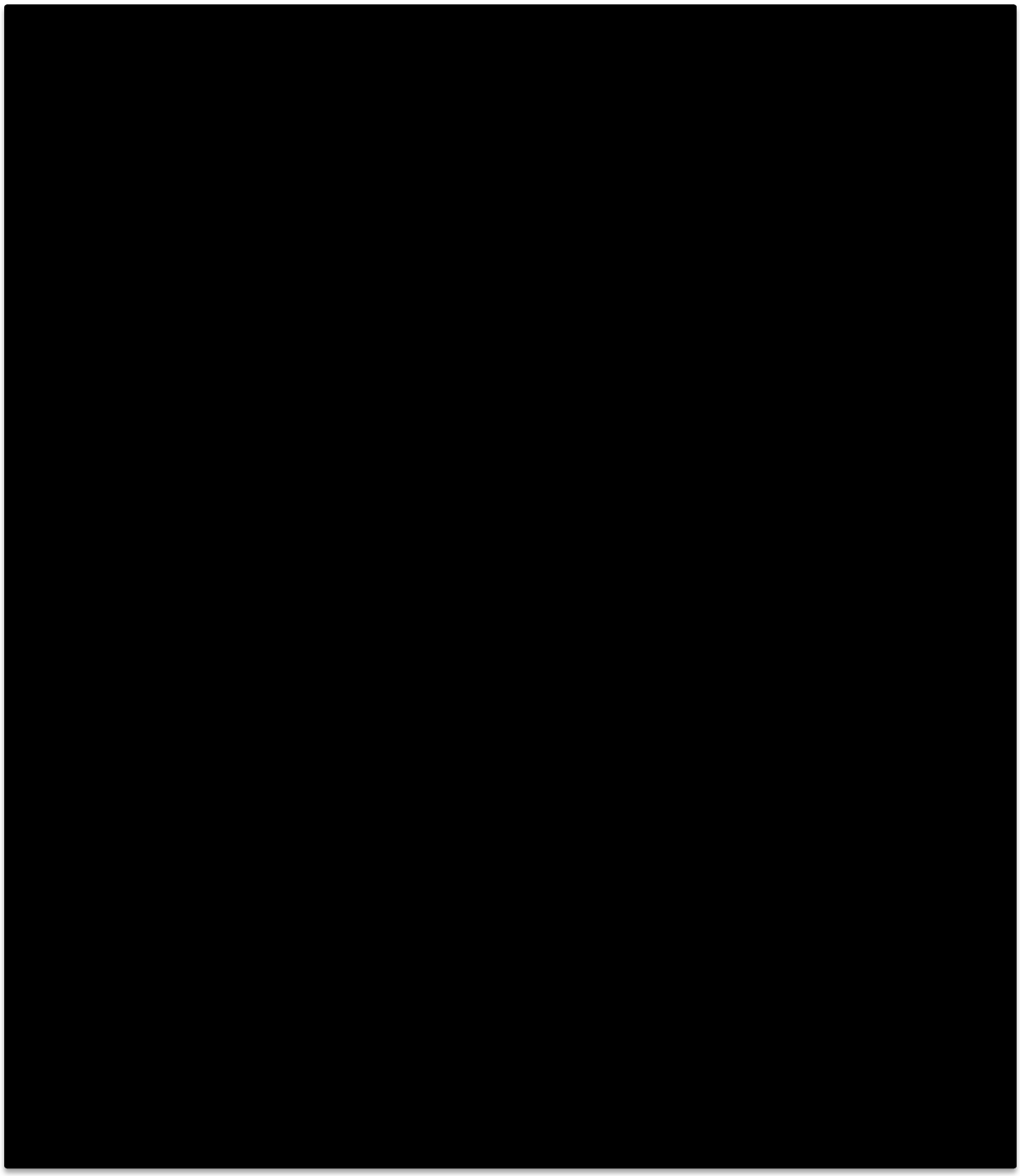


**Figure 4.** Total potentially available cropland within the expected feedstock collection zones.

## 3.0 Process Flow and Energy Balance

ABBK prepared a process flow and energy balance diagram for the Hugoton plant for each feedstock. These are in the files:

[redacted]

## 4.0 ABBK Plant

### 4.1 Plant Inputs and Outputs

The ABBK plant uses an [redacted] process to convert [redacted] to [redacted] sugars. It then uses yeast in a fermentation process to convert the sugars to ethanol. [redacted] In addition to ethanol, the process produces $CO_2$ rich stream, biogas, syrup, stillage cake, and waste water treatment plant (WWTP) sludge. All of these products (with the exception of CO2 rich stream) are utilized in a boiler as fuel to produce steam for a condensing-extracting steam turbine generator to produce electricity and process heat for the plant.

Ethanol Yield – We are using an ethanol yield of [redacted] and [redacted] gal/BD ton for the corn stover and wheat straw feedstocks respectively (see footnote 1).

The ethanol yields for the two feedstock cases are shown in Table 4.

**Table 4. Ethanol Yields from Corn Stover and Wheat Straw**

[redacted]

Biomass – The total biomass used to produce ethanol is somewhat less than the total biomass delivered. The difference in biomass delivered and biomass used to produce ethanol is the biomass fines (produced by grinding biomass for the EH process), [redacted]

The breakdown for natural gas usage is shown in Table 5.

Natural gas – The two feedstock cases assume some natural gas consumption. [redacted]

**Table 5.** ABBK Plant Natural Gas Usage.

[redacted]

Natural gas is also used by the wastewater treatment plant emergency flare. [redacted] The ethanol loadout flare gas demand is a function of the amount of ethanol produced, with the gas demand being estimated at [redacted] mmBtu/yr for corn stover ethanol and [redacted] mmBtu/yr for wheat straw ethanol. The biogas pliot flare gas demand is estimated at [redacted] mmBtu/yr for corn stover ethanol and [redacted] mmBtu/yr for wheat straw ethanol. See process flow diagrams for more details.

The Abengoa cellulosic ethanol process includes cogeneration to supply heat and power for the ethanol process. The cellulosic ethanol process residuals combusted in the biomass boiler produce high pressure steam at [redacted] psig and [redacted] F to supply the steam turbine generator. See steam and fuel energy balances supplied (See file names below).

Medium and low pressure steam extracted from the turbine supply the cellulosic ethanol process heat demand.

[redacted]

Grid electricity – Grid electricity was estimated by assuming [redacted] MWh/yr for the estimated days the plant would be shut down ([redacted] days). Table 6 shows the grid electricity consumption and the on-site generation assumptions for both the corn stover and wheat straw ethanol cases.

**Table 6.** ABBK Plant Grid Electricity Consumption and Onsite Generation.

[redacted]

Electricity provided to the grid is estimated at [redacted] kilowatt-hours per gallon of ethanol for the corn stover pathway and [redacted] kilowatt-hours per gallon of ethanol for the wheat straw pathway. The increased electricity for wheat straw is due to Abengoa's estimate that wheat straw has a [redacted] % higher Btu content per ton than corn stover.[4]

Biomass combustion cogeneration – ABBK combusts unrecoverable process biomass, waste products [redacted] Biogas from the WWTP is also combusted to produce onsite electricity. Table 7 shows the biomass sources for both the corn stover and wheat straw cases.

[4] Wheat straw has less ash than corn stover, which leads to greater heating value

**Table 7.** ABBK Plant Grid Biomass Co-Generation Sources.

[redacted]

WWTP Sludge Heating Value

[redacted]

Corn Stover Syrup HHV vs Wheat Straw Syrup HHV

The primary difference between corn stover and wheat straw is the amount of ash present in the raw material. [redacted]

Table 8 shows the inputs to the ABBK corn stover and wheat straw pathways.

**Table 8.** Inputs to the ABBK Corn Stover and Wheat Straw Pathways.

[redacted]

## 4.2 Chemical Inputs and Emissions

Abengoa conducted an extensive analysis of chemical inputs and GHG emissions from these chemicals. Abengoa estimated each chemical's use in pounds per day, and then found lifecycle GHG emissions for nearly all of the chemicals from a variety of information sources. A spreadsheet called "ABBK Chemicals and Enzymes spreadhseet.xls" contains all of the chemicals used, the emission factors for the chemicals, the source of the emission factors data for each chemical, and the total GHG emissions from these chemicals. The process used to determine chemical emissions was as follows:

- There were two primary sources for information on chemicals: GREET1_2013 [redacted]
- GREET1_2013 provides cradle to gate LCI data for most of the chemicals used in the process. If the chemical did not exist in GREET1_2013, we next used Ecoinvent3 or ABBK on-site analysis. If we did not find the chemical in either of these sources, we did not estimate an emissions factor for the chemical.
- [redacted]
- [redacted]

Transport distances and transport modes for the chemicals are shown in Table 9. All trucking was assumed to be performed with heavy-heavy duty trucks.

**Table 9.** ABBK Fermentation Chemical Transport Distances

[redacted]

The total GHG emissions estimated from all chemicals used at ABBK are 22.05 g $CO_2$/MJ. Since GREET is not configured to calculate all of the fermentation chemical inputs, the emissions are estimated outside of GREET. Lifecycle and transport emissions by chemical type are shown in Appendix 5. (ABBK List of chemicals_v13)

## 5.0 GREET Modifications

We used the default GREET farming and chemical emissions for corn stover. For wheat straw, we assumed the same farming emissions as corn stover, but modified the agricultural chemical inputs for corn stover to those discussed in Section 2.2.

We use the CA_GRV220 default biomass transport distance of 52 miles for corn stover and 36 miles for wheat straw. The urban share of travel was assumed to be the GREET defaults for each feedstock. We also modified the model to include ethanol yield as a user input.

Electricity emissions were estimated assuming the Midwest Average in GREET for farming and agriculture, and Midwest Average for the plant. Electricity provided by the plant to the grid (export) was assumed to replace Midwest Average electricity. Natural gas emissions were estimated by CA_GRV220, as were emissions from corn stover, wheat straw and other products used in the boiler. As noted in Table 6, other products combusted in the boiler include biogas, WWTP sludge, stillage cake, and biomass fines.

Ethanol transport distance by rail to the west Colton California rail yard terminal was estimated at 1,320 miles and was input into GREET. The Colton Rail yard terminal is connected to nearby blending stations by pipeline. We assumed 1 miles for railyard to blending station. We assumed GREET default distances to fueling stations (50 mi).

Model Operation - The CA_GR220 model has been extensively modified so that the majority of inputs and output for ABBK are handled via the EtOH tab.[5] See Appendix 6 for detailed CA_GR220 modifications.

All of the data used in the two scenarios was obtained directly from the ABBK process flow diagrams spreadsheets.

## 6.0 Results

### 6.1 Biogas Fugitive Estimate

[redacted]

### 6.2 Denaturant

According to ASTM Fuel Ethanol Specification (D4806 – 13a) the buyer may ask the denaturer to denature within a specific range (for example, 1.96 to 2.5 volume%). The maximum amount allowed by the ASTM specification is 5 volume %. The US code of Federal Regulations, Title 27, Parts 19, 20, and 21 specifies the denatured fuel ethanol allowed by this specification shall contain a minimum of 1.96 volume % denaturant. [redacted]

[5] The Herbaceous Biomass section is not used because we have eliminated the energy grass as a feedstock for now.

[redacted]

## 6.3 Summary of Emission Results

The carbon intensity of ethanol production from corn stover and wheat straw is shown in Table 10. Detailed GREET results are shown in Appendix 7 and the ABBK CA_GREET2.0 xls model.

**Table 10.** Life cycle Carbon intensity (CI) results for the Corn Stover to ethanol pathway.

| | Corn Stover | Wheat Straw |
|---|---|---|
| | $gCO_2e/MJ$ | $gCO_2e/MJ$ |
| **Region** | **8-SPNO Mix** | **8-SPNO Mix** |
| **Feedstock Farming** | 3.35 | 3.35 |
| **Farming Chemicals** | 10.99 | 8.73 |
| **Feed Transport** | 4.02 | 2.83 |
| **Feed Total** | 18.35 | 14.91 |
| **Region** | **8-SPNO Mix** | **8-SPNO Mix** |
| **Ethanol Production** | 7.74 | 8.36 |
| **Fermentation Chemical** | 22.05 | 22.05 |
| **Electricity Export Credit** | -23.11 | -26.67 |
| **EtOH T&D** | 1.88 | 1.88 |
| **Fuel Total** | 8.56 | 5.62 |
| **Feed + Fuel** | 26.91 | 20.53 |
| **Denaturant** | 2.60 | 2.83 |
| **WTW** | 29.52 | 23.36 |

## Appendix 1

### ABBK Corn Stover Bale Dry Matter Loss Study 2008/2009 – Hugoton, KS

### Introduction

In November 2008, a long-term corn stover storage study was conducted to help determine potential dry matter losses from large square bales stacked field side. Our goal was to monitor the dry matter loss of corn stover bales from month to month over the course of a year to start to initiate some anticipated losses. Data and observations recorded during this study, turned out to be very beneficial and a starting point for further research. Understanding and quantifying dry-matter losses will be very important to the ABBK facility as covered storage can be quite expensive and require potentially greater management.

### Materials and Methods

This site of the study was located [redacted] SW of Hugoton, KS [redacted]

[redacted]

Bales were baled with either a Massey-Ferguson 2190 (Figure 1) or Krone 1290 HPD (Figure 2). Bale weights, moisture, and length were all measured shortly after harvesting. Average moisture was determined by probing across the middle of the bale length wise in four different spots. The average of the four measurements and initial bale weight was then used to determine total dry matter.

The first data collection post-harvest was done on December 15, 2008. We had intentions of weighing at least three bales per month, but due to weather, traveling, and timing, we were not always able to weigh bales every month. We were able to weigh bales on seven different occasions and a total of twenty-six bales were weighed.

Bale weights were obtained using a Gallagher livestock scale (Figure 3). Moisture was determined using a Delmhorst moisture probe. Core samples were also taken from each bale to determine ash/dirt content.

The 30-year average yearly precipitation for Hugoton, KS is right around [redacted]. Historically, most of the rainfall is distributed throughout the spring and summer months, with 65% coming between May-August. Rainfall data recorded at the test site is from November 21, 2008 to September 8, 2009 and was approximately 10.62” (Table 1).

**Figure 1.** Massey Ferguson 2190

**Figure 2.** Krone 1290 HDP

**Figure 3.** Weighing Bales

**Table 1.** Rainfall Data at ABBK Study Site

[redacted]

## Results

[redacted]

[redacted]

[redacted]

[redacted]

**Summary/Conclusions:**

[redacted]

Table 2. ABBK Long-Term Dry Matter Loss Study Results 2008/2009

[redacted]

## Appendix 2

### Wheat Straw Replacement Fertilizer Calculation

Data from ABBK show the actual average N nutrient % of the straw used in the EH process is [redacted]. Figure 1 shows the wheat straw nitrogen content reported on a dry basis. Thus we have used the ABBK N nutrient content when calculating the replacement fertilizer for wheat straw.

[redacted]

**Figure 1.** Wheat Straw Nitrogen wt. % based on data provided by ABBK.

[redacted]

Nutrient Pecentages of Dry Material for Wheat-Winter, for straw

(Average across all sources in database.)

## Appendix 3

Sustainability of biomass residue removal from the field

We evaluated the sustainability of removing wheat straw from continuous cropping of wheat. A literature by Tarkalson, et al review found:

> Consulted data indicate no negative impact on SOC levels by removing small grain straw under irrigated conditions. However, under rain-fed conditions, some above-ground residue is generally needed to maintain SOC levels. Under irrigated, high-productivity conditions, it is likely that higher yield levels provide sufficient below-ground biomass to soils to maintain or gradually increase SOC over time. Significant quantities of nutrients are removed from the field when the straw is removed. Producers need to include costs of future nutrient replacement to determine the true value of the straw.[6]

As indicated earlier, [redacted] of the straw will remain on the field to increase SOC. With regard to the potential need for nutrient replacement, the same study indicates:

> Straw removal enhances the rate of nutrient depletion compared to systems where only grain is removed. Straw contains less P and N than grain, but a higher proportion of K…..when both grain and straw are removed from fields, soil nutrient depletion (especially K) is more rapid, compared with harvesting only grain….fields high in soil K may not immediately require fertilizer inputs to replace the nutrients removed in straw.

[6] Impact of Removing Straw from Wheat and Barley Fields: A Literature Review, Tarkalson, Brown, Kok, and Bjorneberg, Better Crops/Vol 93, (2009, No. 3).

**Appendix 4**

Detailed Plant Inputs

[redacted]

[redacted]

[redacted]

**Appendix 5**

Chemical and Chemical Transport Emissions

[redacted]

**Appendix 5 ctd.**

Chemical and Chemical Transport Emissions

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

**Appendix 6**

Detailed GREET Changes

[redacted]

# Abengoa Bioenergy Biomass of Kansas
# Pathways for Ethanol Derived from
# Corn Stover and Wheat Straw Residues at Hugoton, Kansas

## Input Changes to the CA-GREET Model

Draft CA-GREETv.2.0 (December 2014)

**http://www.arb.ca.gov/fuels/lcfs/ca-greet/ca-greet.htm**

Pursuant to title 17, section 95486 (b)(1) of the California Code of Regulations, alternative models were additionally utilized to compute the life cycle GHG emissions impacts of the proposed pathways. The applicant has conducted its analysis of direct effects on carbon intensity for this pathway using the draft CA-GREET v2.0 (December 2014) model, as well as the ecoInvent database (Version 3).[7] The standard inputs and parameters specified in draft CA-GREETv2.0 remain unchanged, except as noted in the input table below. The input table below specifies the spreadsheet location of the draft CA-GREETv2.0, or ecoInvent inputs and other parameters that were claimed as confidential business information or trade secret by the applicant, but it does not disclose the actual value of such inputs and parameters because they are claimed to be confidential business information or trade secret.

[7] http://www.ecoinvent.org/database/ecoinvent-version-3/

**Input Changes Table 1**

**ABBK Hugoton Corn Stover Pathway**

(Locations of cells containing Confidential Business Information are shown, but the actual values of such confidential information are not disclosed)

| Parameters | Draft CA-GREETv2.0, or ecoInvent | Draft CA-GREETv2.0, or ecoInvent | ABBK Hugoton |
|---|---|---|---|
| | Worksheet Location | Default Cell Value | Corn Stover Pathway Values |
| **Biomass Feedstock** | | | [redacted] |
| Farming Collection Energy | Inputs!K279 | 192,500 Btu/dry ton | [redacted] |
| N Fertilizer Mix | | | [redacted] |
| N Fertilizer mix: Urea (NH2CONH2) | Ag_Inputs!X76 | 31% | [redacted] |
| N Fertilizer mix: Ammonium Nitrate (NH4NO3) | Ag_Inputs!Y76 | 23% | [redacted] |
| N Fertilizer mix: Urea-Ammonium Nitrate Solution | Ag_Inputs!Z76 | 29% | [redacted] |
| N Fertilizer mix: Monoammonium Phosphate | Ag_Inputs!AA76 | 32% | [redacted] |
| N Fertilizer mix: Diammonium Phosphate | Ag_Inputs!AB76 | 4% | [redacted] |
| Dry Matter Loss from corn stover road transport | EtOH!E64 | 2% | [redacted] |
| HDPE Inputs for corn stover | EtOH!O45 | 0 kg/dry tonne | [redacted] |
| **Ethanol Production** | | | [redacted] |
| Corn Stover Ethanol Production Fuel Combustion Shares | | | [redacted] |
| NG engine | EtOH!L320 | 0% | [redacted] |
| NG large industrial boiler | EtOH!L322 | 50% | [redacted] |
| NG small industrial boiler | EtOH!L323 | 50% | [redacted] |
| Fuel Production | | | [redacted] |
| Yield | EtOH!G140 | 80.0 gal/dry ton | [redacted] |
| Energy Inputs | | | [redacted] |
| Biomass Co-gen Fuel source | Fuel_Specs!A139:E148 | N/A | [redacted] |
| Energy Mix | T1Calculator!E9 | U.S. Average (#1) | [redacted] |
| Biomass boiler emission factors | EF!BV6:BV16 | N/A | [redacted] |
| Natural Gas Energy Use for corn stover ethanol | ETOH!CR351 | 0 Btu/gal, LHV | [redacted] |
| Grid Electricity Consumption for corn stover ethanol | ETOH!CR355 | 0 kWh/gal | [redacted] |
| Share of Biomass for corn stover ethanol production | ETOH!CR354 | 60% | [redacted] |
| Corn Stover Chemical and Enzymes inputs | ETOH!CR357:CR362 | N/A | [redacted] |
| Calculation array for corn stover ethanol fermentation | ETOH!CR365:CR379 | See array | [redacted] |
| Corn stover ethanol production Non-combustion Emissions calculation array | ETOH!CT371:CT375 | N/A | [redacted] |
| Share of biomass for ethanol | EtOH!BK164 | 60% | [redacted] |
| Denaturant | Petroleum!B279 | 95% | [redacted] |
| **Net Electricity Export** | EtOH!G140 | -2.56 kWh/gal | [redacted] |
| **Ethanol Transport** | | | [redacted] |
| Rail Transport | T&D!HR105 | 1,400 miles | [redacted] |
| Ethanol truck to rail yard transport distance | T&D!HS105 | 50 miles | [redacted] |

**Input Changes Table 2**

**ABBK Hugoton Wheat Straw Pathway**
**(Locations of cells containing Confidential Business Information are shown, but the actual values of such confidential information are not disclosed)**

| Parameters | Draft CA-GREETv2.0, or ecoInvent | Draft CA-GREETv2.0, or ecoInvent | ABBK Hugoton |
|---|---|---|---|
| | Worksheet Location | Default Cell Value | Wheat Straw Pathway Values |
| **Biomass Feedstock** | | | [redacted] |
| Farming Collection Energy | Inputs!J279 | 131,500 Btu/dry ton | |
| Diesel Fuel Shares for Wheat straw collection | EtOHBS338 | 93% | |
| Electricity Fuel shares for wheat straw collection | EtOHBS344 | 7% | |
| Pesticide use for wheat straw | EtOHBX334 | 30.1 g/dry ton | |
| NO from N fertilizer and above/below ground Wheat Straw biomass | EtOHBT381 | 64.93 g/dry ton | |
| N2O from N fertilizer and above/below ground wheat straw biomass biomass | EtOHBT382 | 97.07g/dry ton | |
| Fertilizer Inputs | | | |
| - Total N | Inputs!J281 | 3,517 g/dry ton | |
| - P2O5 | Inputs!J282 | 1,228 g/dry ton | |
| - K2O | Inputs!J283 | 5,008 g/dry ton | |
| N content in Wheat Straw Residue | EtOH!D50 | 0.6% | |
| N Fertilizer Mix | | | |
| N Fertilizer mix: Urea (NH2CONH2) | Ag_Inputs!X76 | 31% | |
| N Fertilizer mix: Ammonium Nitrate (NH4NO3) | Ag_Inputs!Y76 | 23% | |
| N Fertilizer mix: Urea-Ammonium Nitrate Solution | Ag_Inputs!Z76 | 29% | |
| N Fertilizer mix: Monoammonium Phosphate | Ag_Inputs!AA76 | 32% | |
| N Fertilizer mix: Diammonium Phosphate | Ag_Inputs!AB76 | 4% | |
| Dry Matter Loss from Wheat Straw road transport | EtOH!E64 | 2% | |
| Wheat Straw Field Treatment Dry Matter Loss | EtOH!l39 | 2% | |
| Wheat Straw Field Drying Loss | EtOH!l40 | 5% | |
| Wheat Straw Collection Loss | EtOH!l41 | 3% | |
| HDPE Inputs for Wheat Straw | EtOH!L45 | 0 kg/dry tonne | |
| **Ethanol Production** | | | |
| Corn Stover Ethanol Production Fuel Combustion Shares | | | |
| NG engine | EtOH!S320 | 0% | |
| NG large industrial boiler | EtOH!S322 | 50% | |
| NG small industrial boiler | EtOH!S323 | 50% | |
| Fuel Production | | | |
| Yield | EtOH!GF141 | 80.0 gal/dry ton | |
| Energy Inputs | | | |
| Biomass Co-gen Fuel source | Fuel_Specs!A139:E148 | N/A | |
| Energy Mix | T1Calculator!E9 | U.S. Average (#1) | |

**Input Changes Table 2 Continued**

**ABBK Hugoton Wheat Straw Pathway**
**(Locations of cells containing Confidential Business Information are shown, but the actual values of such confidential information are not disclosed)**

| Parameters | Draft CA-GREETv2.0, or ecoInvent | Draft CA-GREETv2.0, or ecoInvent | ABBK Hugoton |
|---|---|---|---|
| | Worksheet Location | Default Cell Value | Wheat Straw Pathway Values |
| Biomass boiler emission factors | EF!BV6:BV16 | N/A | [redacted] |
| Natural Gas Energy Use for wheat straw ethanol | ETOH!CC351 | 0 Btu/gal, LHV | [redacted] |
| Grid Electricity Consumption for wheat straw ethanol | ETOH!CC355 | 0 kWh/gal | [redacted] |
| Share of Biomass for wheat straw ethanol production | ETOH!CD354 | 60% | [redacted] |
| Wheat Straw Chemical and Enzymes inputs | ETOH!CC357:CC362 | N/A | [redacted] |
| Calculation array for wheat straw ethanol fermentation | ETOH!CC365:CC379 | See array | [redacted] |
| Wheat straw ethanol production Non-combustion Emissions calculation array | ETOH!CE371:CE375 | N/A | [redacted] |
| Share of biomass for ethanol | EtOH!BK164 | 60% | [redacted] |
| Denaturant | Petroleum!B279 | 95% | [redacted] |
| **Net Electricity Export** | EtOH!F140 | -2.56 kWh/gal | [redacted] |
| **Ethanol Transport** | | | [redacted] |
| Rail Transport | T&D!HR105 | 1,400 miles | [redacted] |
| Ethanol truck to rail yard transport distance | T&D!HS105 | 50 miles | [redacted] |

# Appendix 7

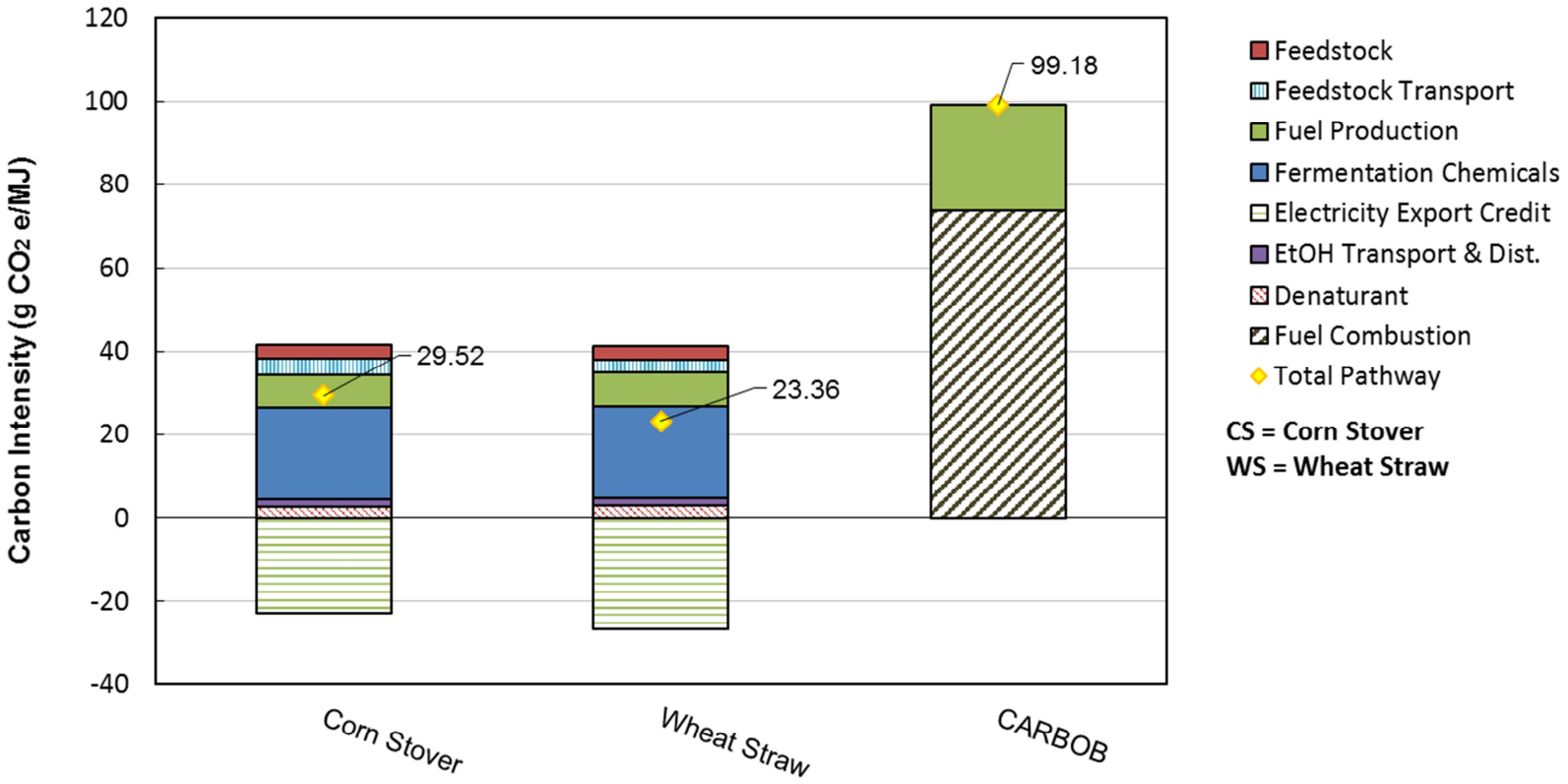
Detailed GREET Results

**Corn Stover Ethanol**

| | Farming | Fertilizers | $N_2O$ in Soil | Biomass T&D | PPE Twine | Total | EtOH production | Electricity credit | Enzymes | Biogas Fugitive | EtOH T&D | Total | Final CI, g/MJ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| [redacted] | | | | | | | | | | | | | |
| g/MJ | 3.17 | 10.99 | 0.00 | 4.02 | 0.18 | 18.35 | 7.51 | -23.11 | 22.05 | 0.23 | 1.88 | 8.56 | 29.52 |

**Wheat Straw Ethanol**

| | Farming | Fertilizers | $N_2O$ in Soil | Biomass T&D | PPE twine | Total | EtOH production | Electricity credit | Enzymes | Biogas Fugitive | EtOH T&D | Total | Final CI, g/MJ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| [redacted] | | | | | | | | | | | | | |
| g/MJ | 3.17 | 8.73 | 0.00 | 2.83 | 0.18 | 14.91 | 8.13 | -26.67 | 22.05 | 0.23 | 1.88 | 5.62 | 23.36 |


120
100
80
60
40
20
0
-20
-40
Carbon Intensity (g CO2 e/MJ)
29.52
23.36
99.18
Corn Stover
Wheat Straw
CARBOB
Feedstock
Feedstock Transport
Fuel Production
Fermentation Chemicals
Electricity Export Credit
EtOH Transport & Dist.
Denaturant
Fuel Combustion
Total Pathway
CS = Corn Stover
WS = Wheat Straw