Lifecycle Emissions of White Energy's Russell Sorghum to Ethanol Plant

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1.0 Executive Summary

White Energy produces 50 million gallons per year of ethanol and 125,000 tons of distillers' grains (DGs) on a dry basis from a plant in Russell, Kansas. Eighty-five percent of the distillers' grains are sold on a wet basis. The primary feedstock for this plant is sorghum, but a secondary feedstock is a waste wheat slurry stream from an adjacent wheat gluten plant. Occasionally, some corn is also used as a feedstock with sorghum and wheat slurry at the ethanol plant. Much of the ethanol from this plant is currently sold into the California market.

California recently approved the Low Carbon Fuel Standard regulations. These regulations require fuel producers to market fuels in California that reduce the carbon intensity of these fuels over time. A 10% reduction in lifecycle carbon intensity is required from 2010 to 2020 for both gasoline and diesel fuel.

The California Air Resources Board (CARB) has estimated lifecycle carbon intensities for a number of different feedstock/fuel combinations, for example, corn-ethanol, cellulosic-ethanol, and biodiesel made from soybeans. CARB used the Argonne GREET model for production and transportation emissions for these feedstock/fuel combinations, and used GTAP modeling to estimate greenhouse gas (GHG) emissions due to land use changes. CARB has not yet estimated lifecycle emissions for ethanol made from sorghum. The purpose of this study is to estimate lifecycle emissions for the Russell plant.

Our estimates of the lifecycle emissions are shown in Table ES-1. We show the emissions from a dry mill corn ethanol plant with 100% dry DGs for comparison. The results show that the GHG emissions for the Russell plant utilizing sorghum and waste wheat slurry are 63.55 g/MJ, as compared to 98.36 g/MJ for the corn dry mill with dry DGs. The GHG emissions from this plant are lower than corn due to 3 reasons (1) use of the waste wheat slurry stream which has no farm, chemical, or land use emissions, (2) lower farm and agriculture chemical inputs for sorghum in Kansas, and (3) lower plant emissions due to the distillers' grains being provided on a wet basis.

Table ES-1. GHG Lifecycle Emissions for the Russell Plant (average of 2008 and 2009)		
Well-to-Tank Ethanol Cycle Components	Russell GHG (gCO2e/MJ) (Sorghum +Wheat slurry), Wet DGs	Corn Dry Mill GHG (gCO2e/MJ) with dry DGs
Farming	3.80	5.65
Ag Chemical Production	20.10	30.20
Transport	1.62	2.22
Ethanol Production	24.17	38.30
Ethanol T&D	2.70	2.70
Co-Products	-12.43	-11.51
Sub Total	39.95	67.56
Denaturant	0.80	0.80
Land Use Change	22.80	30.00
Total	63.55	98.36

We did not perform an analysis of the indirect land use emissions of sorghum used for making ethanol. However, CARB intends to use the same value for sorghum that is used for corn, 30 g/MJ. The 30 g/MJ is intended for use in a plant that utilizes all corn or sorghum as a feedstock. The Russell plant utilizes the waste wheat stream, which should not have land use emissions applied. Over the last two years, the waste wheat stream has averaged 24% feedstock input. The land use estimate in Table ES-1 was computed by assuming a 24% reduction in the land use value for corn of 30 g/MJ.

White also anticipates providing both dry and modified DGs in the future from this plant. The dry DGs provided would have a moisture content of 12%, and the modified DGs would have a moisture content of 50%. The current wet product is provided at a moisture content of 65%. For corn ethanol, CARB estimates a 8.3 g/MJ increase in emissions for dry DGs. Using the difference in CARB's wet and dry values to interpolate the modified product at 50% moisture, the increase in emissions from the wet DGs would be 2.3 g/MJ.

We further developed the estimated emissions (including land use) from the plant with the individual year results, where the wheat slurry fraction varied between 20% and 28%, and used these estimates to develop emissions at a variety of wheat slurry fractions. Table ES-2 shows the overall CI of the Russell plant at different wheat slurry fractions and DG types.

Table ES-2. Carbon Intensities of Russell Plant at Different Wheat Slurry Fractions (includes land use effect)					
	Wheat Slurry Fraction				
	15%	20%	25%	30%	35%
Wet DGs	69.36	66.16	62.96	59.76	56.56
Dry DGs	77.66	74.46	71.26	68.06	64.86
Modified DGs	71.66	68.46	65.26	62.06	58.86

2.0 Introduction

White Energy produces ethanol from a plant in Russell, Kansas. The primary feedstock for this plant is sorghum, but a secondary feedstock is a wheat slurry stream from an adjacent wheat gluten plant. Occasionally, some corn is also used as a feedstock with sorghum and wheat slurry at the ethanol plant. Much of the ethanol from this plant is currently sold into the California market.

California recently approved the Low Carbon Fuel Standard regulations. These regulations require fuel producers to market fuels in California that reduce the carbon intensity of these fuels over time. A 10% reduction in lifecycle carbon intensity is required from 2010 to 2020 for both gasoline and diesel fuel.

The California Air Resources Board (CARB) has estimated lifecycle carbon intensities for a number of different feedstock/fuel combinations, for example, corn-ethanol, cellulosic-ethanol, and biodiesel made from soybeans. CARB used the Argonne GREET model for production and transportation emissions for these feedstock/fuel combinations, and used GTAP modeling to estimate GHG emissions due to land use changes.
The purpose of this study is to estimate lifecycle emissions for the Russell plant, which is primarily sorghum-based.

This report is divided into the following sections:

- Background
- Overview of Russell Plant
- Sorghum Farming GHG Emissions
- Ethanol Plant GHG Emissions
- Results
- Land Use Emissions

3.0 Background

CARB uses the GREET model to estimate lifecycle emissions of various feedstocks and processes. The GHG emissions for corn ethanol made in a dry mill with 100% dry distillers' grains (DGs), and using Midwest electricity, are shown in Table 1 below. [1]

Table 1. GHG Emissions Summary for Dry Mill Corn Ethanol	
Corn Ethanol Fuel Cycle Components	Emissions (g/MJ), Dry Mill
Corn Farming	5.65
Ag Chemicals Production	30.20
Corn Transportation	2.22
Ethanol Production	38.3
Ethanol Transportation and Delivery	2.7
Co-Products	-11.51
Total, well-to tank	67.6

Source: "Detailed California-Modified GREET Pathway for Corn Ethanol", February 27, 2009, Version 2.1

The table shows 5.65 g/MJ for corn farming, 30.2 for agriculture chemicals production, 38.3 g/MJ for ethanol production, and -11.51 g/MJ for co-products (distillers' grains). For the sorghum analysis, these are the categories of emissions that should be developed in a manner consistent with the corn analysis. For this analysis, we will assume that sorghum transportation and ethanol transportation and delivery (T&D) are the same as for corn.

The corn farming primary energy inputs are shown in Table 2. These are used to develop the GHG emissions for corn farming.

Table 2. Primary Energy Use for Corn Farming			
Fuel Type	Fuel Share	Formula	Primary Energy Input (BTU/bu)
Residual Oil	0.0%	0.00 * 12,635	0
Diesel fuel	45.2%	0.452 * 12,635	5715
Gasoline	18.2%	0.182 * 12,635	2298
Natural gas	14.5%	0.145 * 12,635	1835
Coal	0.0%	0.00 * 12,635	0
LPG	16.8%	0.168 * 12,635	2119
Electricity	5.3%	0.053 * 12,635	667
Direct energy consumption for corn cultivation (BTU/bu)			12,635

Source: Table 1.01 of CARB Corn Ethanol Report

The primary energy inputs for corn farming are translated through a series of steps into GHG emissions, as shown in Table 3.

Table 3. GHG Emissions from Corn Farming		
Species	Emissions (g/bu)	GHG (g/mmBTU)
VOC	2.050	31
CO	40.688	308
CH4	2.25	271
N2O	0.025	36
CO2	1,103	5,315
Total GHG (g/mmBTU)		5,960
Total GHG (g/MJ)		5.65

Source: Table 1.09, CARB Corn Ethanol Report

The farming emissions for sorghum can be developed in a similar manner. If values for sorghum are determined for Table 2, then the same conversions and translations can be done to develop the emissions in Table 3 for sorghum.

The agriculture chemical production emissions for corn ethanol are shown in Table 4.

Table 4. Agriculture Chemical Production Emissions for Corn Ethanol		
Chemical Type	Chemical input (g/bu)	Dry Mill WTT Energy (Btu/mmBtu)
Nitrogen fertilizer	420	92,787
Phosphate fertilizer	149	9,596
Potash	174	7,086
Lime	1202	44,805
Herbicide	8.1	10,397
Insecticide	0.68	1,031
Total		165,703

Source: Table 2.01, CARB Corn Ethanol Report

Total GHG emissions from the production and use of these chemicals are shown in Table 5.

Table 5. Total GHG Emissions for Agriculture Chemical Use for Dry Mill	
Component	GHG Emissions (g/MJ)
Fertilizers	10.3
Herbicide	0.8
Pesticide	0.08
Soil N2O	15.91
CO2 from CaCO3	2.41
CO2 from urea	0.64
VOC and CO	0.06
Total	30.2

Source: Table 2.07 of CARB Corn Ethanol Report

As shown in Table 5, 85% of the GHG emissions are from the fertilizers (soil N2O is from nitrogen fertilizer). For sorghum, we will need to find the appropriate loadings of fertilizer, herbicide, and insecticide to develop agriculture chemical emissions for sorghum.

Table 6 shows the energy inputs to a corn ethanol dry mill plant.

Table 6. Primary Energy Inputs to a Corn Ethanol Plant		
Fuel Type	Fuel Share	Primary energy input (Btu/gallon)
Natural gas	89.8%	32,330
Electricity	10.2%	3,670
Total	100%	36,000

Source: Table 4.01 of CARB Corn Ethanol Report

These primary energy inputs translate to the GHG emissions for the plant as shown in Table 7.

Table 7. Total GHG Emissions from Dry Mill Corn Ethanol Plant		
Fuel Type	CO2 in g/gal	CO2 eq/mmBtu
Natural Gas	2,051	26,880
Electricity – as feedstock	884	11,591
Electricity, as fuel, VOC+CO+CH4+N2O	7.7	1,911
Total, g CO2 eq/mmBTU		40,383
Total, g CO2 eq/MJ		38.3

Source: Table 4.05 of CARB Corn Ethanol Report

For the Russell Plant, we also need to evaluate the primary energy inputs to determine similar emissions.

Table 8 shows GHG emissions for co-product credits for a dry mill plant. For corn, GREET estimates that 5.34 lbs of dry DGs are produced for each gallon of anhydrous ethanol produced.

Table 8. Dry Mill Co-Product Emission Credits	
Displaced Product	Feed corn credit
VOC	-0.55
CO	-5.00
CH4	-0.58
N2O	-1.38
CO2	-492
GHGs	-927
GHG g CO2 eq/mmBTU	-12,145
GHG g CO2 eq/MJ	-11.5

Source: Table 6.05 of CARB Corn Ethanol Report

The Russell plant also produces DGs from sorghum, and we need to estimate the co-product credit of these DGs in a similar manner.

4.0 Overview of Russell Plant

The Russell Plant is located on a 60-acre parcel of land near Russell, Kansas. The plant is located within an industrial park that consists of the fuel grade ethanol facility, a wheat gluten production plant, wastewater treatment plant, a gas turbine electric generation plant and a pet food plant. While all aspects of these separate are functionally independent facilities, they are interrelated.[1] A process flow diagram for the plant is shown in Appendix 1. Appendix 1 also contains a list of combustion equipment.

U.S. Energy Partners, LLC operates and maintains the Russell Plant and the wheat gluten milling facility. The gas turbines with heat recovery steam generators (HRSGs) are the property of the local municipal electric company and the pet food plant is owned and operated by a third party. Currently, the Russell Plant is designed as a 40 million gallons per year (mgy) dry grind ethanol plant that produced [redacted]. The plant consumes approximately [redacted] and receives up to 30 percent of its starch feed stock from the wheat gluten plant in the form of a slurry that is pumped to the slurry tank at the ethanol facility.

The primary outputs from the plant are fuel grade ethanol that is denatured with two percent natural gasoline and distillers' grains (DGs). Most of the DGs are sold as wet DGs, where the wet cake is mixed with syrup and is comprised of approximately 66 percent moisture. A rotary DG dryer is installed at the site, however, the plant takes advantage of the energy savings by having the ability to sell the DGs as wet cake to the local feed market.

The primary outputs of the Wheat Gluten facility are vital wheat gluten for the baking industry, wheat middlings for animal feed, and waste by-product starch slurry. [redacted]

Steam energy is produced in two natural gas fired boilers with a steam capacity of approximately 100,000 lbs per hour at a design pressure of 150 psig. Flue gas from the boiler passes through a feedwater economizer to improve boiler thermal efficiency. Each boiler is equipped with a separate exhaust stack. In addition to these boilers, steam can be produced from the Heat Recovery Steam Generators (HRSGs) that are installed as part of the gas turbine generator power plant at the site. The boilers and HRSGs are joined in a common header to provide steam service for the Russell Plant, however, due to cyclic operation of these gas turbines, steam from the Russell plant is primarily produced using the permanent plant boiler and the rental boiler.

4.1 Wheat Gluten Plant Synergies

[1] The wastewater treatment plant, ethanol facility and wheat gluten facility are all under the USEP umbrella.

[redacted]

Table 9 shows the feedstock usage, ethanol production, distillers' grains production, and energy usage at the Russell facility. We show the DG production on a wet and dry basis. To convert wet DGs to dry, we use a factor of 0.35, and to convert the dry DGs to a dry basis, we use a factor of 0.88. [2] To convert Midds to dry, a factor of 0.5 is used.

[2] Wet DGS at the Hereford plant are provided to local feed markets with a moisture content of 65%. Testing is conducted bi-hourly to ensure accuracy within plus or minus 1%. Thus, to convert wet DGs to dry matter, we multiply by (1-0.65) = 0.35. Dry DGs are provided at 12% moisture content, thus to convert dry DGs to dry matter we multiply by (1-0.12)=0.88.

Table 9. Feedstock and Energy Use at the Russell Plant			
Ethanol Plant	Units	2008	2009
Feedstock Input, Ethanol Output and DG Output			
Grain usage, sorghum	Bu	[redacted]	[redacted]
Grain usage, corn	Bu	[redacted]	[redacted]
Grain usage, starch equivalence	Bu	[redacted]	[redacted]0
Total grain (incl starch)	Bu	[redacted]	[redacted]
Starch fraction of total grain		[redacted]	[redacted]
Ethanol production	Gal	[redacted]	[redacted]
Wet DGs Production	Tons	[redacted]	[redacted]
Dry DGs Production	Tons	[redacted]	[redacted]
Midds Production	Tons	[redacted]	[redacted]
Wet DG Production (dry basis)	Tons	[redacted]	[redacted]
Dry DG Production (dry basis)	Tons	[redacted]	[redacted]
Midds Production (dry basis)	Tons	[redacted]	[redacted]
Tot. DG Production (dry basis)	Tons	[redacted]	[redacted]
Percent DG wet		[redacted]	[redacted]
Energy Usage			
Natural Gas	mmBtu	[redacted]	[redacted]
HRSG	mmBtu	[redacted]	[redacted]
Electricity	kWh	[redacted]	[redacted]

The table shows 13.4 and 12.4 milion bu of sorghum used in 2008 and 2009, respectively. In 2009, the facility also used nearly 1 million bu of corn. Between 2008-2009, the wheat slurry input to the facility was the equivalent of [redacted] sorghum, and over the two-year period, the starch fraction is 24%. Between 2008 and 2009, the wet DGs were 82-83% of total DGs.

[redacted]

Table 10. Ethanol and Distillers' Grain Yields			
Parameter	2008	2009	2-Year Average
Ethanol yield per bu sorghum + corn, no starch	[redacted]	[redacted]	[redacted]
Ethanol yield per bu with starch	[redacted]	[redacted]	[redacted]
Distillers' grain yield, dry, lbs per bu corn + sorghum	[redacted]	[redacted]	[redacted]
Distillers' grain yield, dry, lbs per bu all (corn + sorghum + starch equiv)	[redacted]	[redacted]	[redacted]
Distillers' grain yield, dry, per gallon ethanol	[redacted]	[redacted]	[redacted]

The feedstocks for the Russell plant are sorghum, sometimes a small amount of corn, and the wheat slurry waste stream. We propose to estimate the farming emissions on sorghum alone. The wheat slurry stream is a waste stream, and if it were not used in the ethanol plant, it would be disposed of, so its farming emissions are not relevant here. Corn is not usually used, and when it is, the fraction of corn used is small. It is important to note, however, that the ethanol plant energy GHG emissions will reflect the energy needed to convert the wheat slurry waste stream to ethanol.

5.0 Sorghum Farming Emissions

This section discusses sorghum farming emissions, which include farming and farm chemical production and emissions. Data from this section will be input into the most recent version of the CARB GREET model (CA_GREET1.8B_DEC09.XLS) to estimate overall lifecycle emissions. The section is divided into the following subsections:

- Sorghum yields
- Energy use during farming
- Chemical use

5.1 Sorghum Yields

The state of Kansas is divided into agricultural districts, and the Russell plant is located in District 50. Nearly all of the sorghum that comes into the plant is derived from this district. The sorghum yield for Kansas District 50 from 2005 to 2009 is shown in Table 11. [2]

Table 11. Sorghum Yields in District 50 of Kansas

Year	Yield (bu/acre)
2004	93
2005	71
2006	56
2007	85
2008	91
2009	92
Average, 2004-2009	81.3
Average, last 3 years (2007-2009)	89.3

The results show yields to be 81.3 bu/acre for the last 6 years, and 89.3 bu/acre for the last 3 years. We propose to use the yields in the last 6 years from District 50 for developing lifecycle emissions. [3]

5.2 Fuel/Energy Use

The GREET model requires that the residual oil, diesel, gasoline, liquefied petroleum gas (LPG), electricity, coal, and natural gas consumed in farming be quantified. There are several sources of farm energy use for sorghum, as follows:

- U.S. Department of Agriculture Surveys
- FASOM Model

[3] Further investigation into the supply of sorghum for this plant showed that sorghum was coming from eight counties around Russell. When we averaged the yields of these 8 counties over six years, the average yield was 88.7 bu/acre. We believe the 81.3 bu/acre estimate is therefore conservative. See Appendix 2 for additional details.

- Kansas State University

In this section, estimates from these sources will be compared, and final estimates will be determined for use in GREET modeling.

5.2.1 U.S. Department of Agriculture

Diesel and gasoline are generally used to power equipment in order to prepare fields, plant, fertilize, and harvest sorghum. Electricity is generally used for irrigation (where used), and propane or natural gas is used in drying sorghum. Sorghum can tolerate a drier climate than corn (grown mainly in Kansas and Texas), and it is a drier crop, so our expectation is that the electricity and natural gas used would be significantly lower than used for corn.

The most recent survey that included sorghum is a relatively old survey conducted in 1995. The USDA-ERS 1995 sorghum farming survey reported the values as shown in Table 12 for the Central Plains (Kansas-Nebraska-Missouri), Southern Plains (Oklahoma, Arkansas, Texas) and all U.S. areas. [3]

Table 12. Sorghum Farming Energy Use, 1995 USDA Survey

Energy Source & Units	Central Plains (includes Kansas)	Southern Plains	U.S. Average
Diesel (gallons/acre)	4.53	6.88	5.39
Gasoline (gallons/acre)	3.06	3.16	3.09
Electricity (kWh/acre)	0.15	Too variable to report	0.46
Liquefied Petroleum Gas (gallons/acre)	Not reported	Not reported	Not reported
Natural Gas (cubic feet/acre)	Too variable to report	2240	900

Diesel use in Kansas is somewhat lower than the U.S average, and gasoline usage is about the same. Electricity use appears to be lower in Kansas than for the U.S average for this survey. The survey shows that the amount of natural gas use for sorghum in the central plains was too variable to report during the time of this survey, whereas some natural gas was used in the southern plains. This could have been due to rainfall in the southern plains during the time period of this survey, which could have made the crop wetter, resulting in a need to dry the crop.

5.2.2 FASOM Model

The FASOM model was utilized by the EPA in determining the net change in total agriculture emissions due to the renewable fuel standard. [3,4] The model contains estimates of energy use by crop type.

Table 13 shows values that were derived from the FASOM model, as given in the EPA RFS2 report. [4] These values represent the U.S. average energy consumption for sorghum farming, and not necessarily the values in Kansas or District 50 of Kansas, where the plant is located.

Table 13. Farming Energy Use, FASOM Model	
Energy Source & Units	Sorghum (U.S. Average)
Diesel (gallons/acre)	9.07
Gasoline (gallons/acre)	3.56
LPG (gallons/acre)	Not Available
Electricity (kWh/acre)	5.79
Natural Gas (cubic feet/acre)	Not Available

FASOM shows much higher diesel use and somewhat higher gasoline use than the 1995 USDA survey for sorghum. Electricity use is also much higher than the USDA estimates. FASOM also does not contain estimates for LPG and natural gas, so we are concluding that little natural gas or propane is used in farming sorghum.

5.2.3 Kansas State University

Research was conducted on diesel fuel use at sorghum farms in Kansas by Dr. Richard Nelson of Kansas State University in 2008-09. [5] The values are shown in Table 14. Diesel consumption can vary significantly by region. For reference, Russell County is located in the North Central Region. The diesel fuel consumption here is 4.7 gal/acre, which is lower than FASOM but very similar to the 1995 USDA survey for the Central Plains.

Table 14. Sorghum Farming Diesel Fuel Use, Kansas	
Kansas Region	Diesel (gallons/acre)
Western, Lister Planted	4.81
Western, Surface Planted	3.60
North Central (District 50 located here)	4.71
South Central	6.16
Northeast	4.36
Southeast	6.51

Although the diesel and gasoline values in these two tables are within a factor of 2 of the USDA numbers given in Table 1, the FASOM sorghum electricity value is nearly 39 times larger. Moreover, no data for LPG or natural gas usage could be found.

Based on the data in Tables 11-13, it appears that the USDA values for sorghum are reasonable. The values used in further GREET modeling are summarized in Table 15.

Table 15. Sorghum Farming Energy Use, Modified CA-GREET Model		
Energy Source & Units	Sorghum	Source
Diesel (gallons/acre)	4.71	Kansas State
Gasoline (gallons/acre)	3.06	1995 USDA
LPG (gallons/acre)	0	Assumption
Electricity (kWh/acre)	0.15	1995 USDA
Natural Gas (cubic feet/acre)	0	Assumption

We think that based on the data it is likely that little electricity or natural gas is used for sorghum in District 50. However, to test the impact of this assumption on the results, we will examine the lifecycle emissions impact of utilizing the electricity emissions from FASOM of 5.79 kWh/acre, and the U.S. average natural gas usage from USDA of 900 cu ft/acre. All other energy values for this case are the same as in Table 15.

5.3 Fertilizer Use

The amounts and types of fertilizer applied for sorghum farming depends on a wide range of factors, including desired yield, tillage method, and crop rotation. AIR obtained the application recommendation information from Kansas State University. [6] These values, shown in Table 16, are based on the assumption that soybeans were planted the previous season.

Table 16. Kansas State Fertilizer Application Recommendations						
Fertilizer (pounds/acre)	North Central Desired Yield			South Central Desired Yield		
	70 bu/a	90 bu/a	110 bu/a	60 bu/a	70 bu/a	100 bu/a
Nitrogen (anhydrous)	41	62	78	59	77	95
Nitrogen (N)	10	12	15	10	15	20
Phosphate (P2O5)	32	41	50	27	36	45
Potash (K20)	0	0	0	0	0	0
Lime (CaCO3)	500	500	500	500	500	500

AIR also obtained farming survey data from the USDA-ERS for Kansas and the adjoining states. These application rates are summarized in Table 17. [7]

Table 17. USDA-ERS Fertilizer Application Rates		
Fertilizer	Region	Application Rate
Nitrogen (N)	Kansas	76.1 pounds/acre
Phosphate (P2O5)	Kansas	29.2 pounds/acre
Potash (K20)	Kansas	Not Available
	Oklahoma	21.8 pounds/acre
	All Sates	27.2 pounds/acre
Percent Treated with Lime, annual (CaCO3)	Kansas	10.9%

As these two tables show, there is fairly good agreement in the amounts of nitrogen and phosphate to apply, but considerable disagreement on potash rates. (The USDA-ERS Kansas potash and lime rates are not available due to insufficient data.) Discussions with Kansas State and USDA personnel indicate that soil tests are usually taken to determine the need for these fertilizer types. Thus, the rates can vary significantly from one season to the next. In addition, the Kansas recommendations assume that soybeans were planted during the last rotation.

AIR believes that combining this information is the best approach for the modeling input. Thus, the values in Table 18 were used for the sorghum fertilizer rates for the modified CA-GREET model.

Table 18. Sorghum Farming Fertilizer Rates, Modified CA-GREET Model

Fertilizer	Application Rate, lbs/acre	Application Rate, g/bu @ 81.3 bu/acre	Source
Nitrogen (N)	76.1	424.6	Table 17
Phosphate (P2O5)	29.2	162.9	Table 17
Potash (K20)	10.9	60.8	Average of Table 16 and Table 17, Oklahoma
Lime (CaCO3)	54.5	304.1	Table 16 rate times Table 17 percent treated

5.4 Pesticide Use

The amounts and types of herbicide and insecticide used in sorghum farming were obtained from the USDA-ERS and Kansas State University. They are summarized in Table 19 below. [6,7]

Table 19. Kansas Pesticide Application Rates

Type	USDA-ERS	Kansas State
Herbicide	2.188 pounds/acre	2.20 pounds/acre
Insecticide	2.188 pounds/acre	1.04 pounds/acre

The GREET model determines the herbicide energy use based on the following four products: Atrazine, Metolachlor, Acetochlor, and Cyanazine. AIR was not able to determine the product makeup of the herbicide amounts listed in Table 18. Therefore, it was assumed that the GREET default weighting of 25% for each product was applicable to sorghum.

AIR finds it interesting that the USDA reports the exact same application rate for herbicides and insecticides. Therefore, it was felt that using the averages would be best. Therefore, the pesticide values shown in Table 20 were used for the modified CA-GREET model.

Table 20. Sorghum Pesticide Application Rates, CA-GREET			
Type	Application Rate, lbs/acre	Application rate, g/bu	Source
Herbicide	2.194	12.24	Average of Table 19 entries
Insecticide	1.614	9.004	Average of Table 19 entries

5.5 Other Assumptions

The CA-GREET model requires several additional farming-related inputs:

- The nitrogen content of the above and below ground biomass
- Vehicle type and distances for harvesting and delivery grain to the ethanol plant
- CO2 emissions from direct land use changes
- Urban shares of transportation mode activities
- Co-product credits

AIR discussed these aspects with USDA personnel. Although no corroborating data could be cited, they believed that these parameters should be similar to corn farming. As a result, the values in Table 21 were used in the modified CA-GREET model.

Table 21. Miscellaneous Sorghum Farming Parameters, CA-GREET	
Parameter	Value
Nitrogen content of the above and below ground biomass	141.6 grams/bushel (assumed to be same as corn)
Vehicle type and distances for harvesting and delivery of grain to the ethanol plant	MHDT, 10 miles from field to stack MHDT, 40 miles from stack to plant
CO2 emissions from direct land use changes	None, as long as land is always used for farming
Urban shares of transportation mode activities	0% for all transportation modes
Co-product credit	Equivalent to corn ethanol displacement method

6.0 Ethanol Plant Energy Use

The CA-GREET model requires that grain and energy usage and ethanol production quantities are input. White Energy supplied the information for the Russell County plant for 2008 through 2009 as shown in Table 22.

Table 22. White Energy Plant Parameters

Parameter & Units	2008	2009	Average
Sorghum Usage (bushels)	[redacted]	[redacted]	[redacted]
Corn Usage (bushels)	[redacted]	[redacted]	[redacted]
Total Grain Usage w/o starch (bushels)	[redacted]	[redacted]	[redacted]
Ethanol Production (gallons)	[redacted]	[redacted]	[redacted]
DG Production (tons, dry basis)	[redacted]	[redacted]	[redacted]
Natural Gas & HRSG (mmBTU)	[redacted]	[redacted]	[redacted]
Electricity (kWh)	[redacted]	[redacted]	[redacted]

GREET requires some of these values in somewhat different units, for example, it requires energy use in kWh/gal. The converted values are shown in Table 23. For ethanol yields in g/bu, we are utilizing the yields that were estimated by dividing the total ethanol from the plant by the sum of the sorghum and corn bushels. We are not including the equivalent bushels from the wheat starch slurry waste stream.

Table 23. CA-GREET Plant and Ethanol Production Parameters

Parameter & Units	2008	2009	Average
Share of Sorghum Ethanol Plant that is Dry Mill	[redacted]	[redacted]	[redacted]
Ethanol yield, gallons/bushel, without starch slurry	[redacted]	[redacted]	[redacted]
Energy Use: NG, Coal, and Biomass, Btu/gallon	[redacted]	[redacted]	[redacted]
Share: NG	[redacted]	[redacted]	[redacted]
Share: Coal	[redacted]	[redacted]	[redacted]
Share: Biomass	[redacted]	[redacted]	[redacted]
Electricity Demand, kWh/gallon	[redacted]	[redacted]	[redacted]
Total Ethanol Production Energy: Btu/gallon	[redacted]	[redacted]	[redacted]
Electricity Share of Total Ethanol Production	[redacted]	[redacted]	[redacted]

6.1 Electricity Mix

This analysis uses the Midwest average utility mix. However, White Energy obtained information on the mix of electricity supplied in Russell, Kansas, which are shown in Table 24. There are somewhat more renewables used in this part of Kansas than the estimates used for the Midwest in the GREET model. Appendix 3 shows a letter from the city that verified this renewable mix. If the local utility mix were used, emissions from the plant would be lower.

Table 24. Electrical Production Mix for Russell, Kansas		
Source	GREET "Midwest"	Russell, KS
Residual Oil	[redacted]	[redacted]
Natural Gas	[redacted]	[redacted]
Coal	[redacted]	[redacted]
Nuclear	[redacted]	[redacted]
Biomass	[redacted]	[redacted]
Renewable (hydro, wind, and geothermal)	[redacted]	[redacted]

7.0 Modified CA-GREET Results

In order to compute the sorghum emissions via GREET, numerous modifications were made to the model. New sorghum-specific calculations and/or data sections were installed in the following spreadsheet tabs: Inputs, T&D_Flowcharts, T&D, Urban_Shares, Fuel_Prod_TS, Ag_Inputs, and EtOH. A list of changes made to the GREET model for Russell is shown in Appendix 4. The following sections develop average emissions for 2008 and 2009, but the individual year emissions are shown in Appendix 5.

7.1 Farm Emissions

The CARB report on corn ethanol contains three key summaries in Tables 1.01 (Farm Operation Energy Use), 1.09 (Farming GHG Emissions), and B (Ethanol Fuel Cycle GHG Emissions). Comparable tables were created for the sorghum ethanol production using the modified CA-GREET model and the inputs described in this report for the average of 2008 and 2009. These three tables, showing both the corn and sorghum results, are given below in Table 25.

Table 25. Farm Operation Energy Use for Sorghum

	Sorghum		Corn (Dry Mill)	
Fuel Type	Fuel Share	Primary Energy Input (Btu/bu)	Fuel Share	Primary Energy Input (Btu/bu)
Residual Oil	0.00%	0	0.00%	0
Diesel Fuel	62.97%	7,442	45.23%	5,715
Gasoline	36.97%	4,369	18.19%	2,298
Natural Gas	0.00%	0	14.53%	1,835
Coal	0.00%	0	0.00%	0
LPG	0.00%	0	16.77%	2,119
Electricity	0.05%	6	5.28%	667
Total Direct Energy Use for Cultivation		11,817		12,635

Table 25 shows that the sorghum farming energy use, on a per bushel basis, is about 6.5% lower than that for corn. Table 26 shows the GHG emissions for the total farming component, as estimated with the modified GREET model based on the fuel types in Table 24. The overall farming GHG emissions on an energy-specific basis are lower than corn, partly because the direct energy use is lower (see Table 23), and also because the wheat slurry waste stream adds extra energy without a farm component.

Table 26. Farming GHG Emissions (from modified GREET)				
	Sorghum		Corn (Dry Mill)	
Emissions Species	Emissions (g/bu)	GHG (gCO2e/mmBtu)	Emissions (g/bu)	GHG (gCO2eq/mmBtu)
VOC	3.28	36.20	2.05	31
CO	74.38	414.29	40.69	308
CH4	1.38	122.12	2.25	271
N2O	0.02	16.19	0.025	36
CO2	963.78	3,416.17	1,103	5,315
Total GHG (g CO2e/mmBtu)		4,004.97		5,960
Total GHG (g CO2e/MJ)		3.80		5.65

The farming emissions in Table 26 are 33% less than for corn. This relative difference is because the estimates in Table 25 are 6.5% lower (factor of 0.935), and we are not counting the agriculture emissions of the starch slurry (factor of 0.76 to account for fraction of sorghum + corn to total bushels). Multiplying 0.935 and 0.76, we obtain 0.71, which indicates a 29% reduction from corn, close to our estimated 33% reduction.

7.2 Agriculture Chemical Emissions

Agriculture chemical emissions for the average of 2008 and 2009 are summarized in Tables 27, 28, and 29. These are similar to Table 2.05, 2.06, and 2.07 in the CARB Corn Ethanol report. GHG emissions for the chemicals alone are shown in Table 27. Table 28 shows a summary of N2O emissions conversion. Table 29 shows the summary of these two sources of emissions by fertilizer type. Total chemical input emissions are 20.10 g/MJ. The emissions are lower than for corn primarily because of the effect of the starch slurry. [4]

[4] When we multiply the 30.20 g/MJ from corn by the 0.76, we obtain 22.9 g/MJ, which is close to the 20 g/MJ. Thus, the major effect is the starch slurry effect, but slightly lower nitrogen input per MJ is for sorghum is probably another factor.

Table 27. Calculated GHG Emissions from Production of Agricultural Chemicals for Sorghum							
GHG Type	Nitrogen	P2O5	K2O	Ca CO3	Herbicide	Insecticide	Total
	g/bu						
CH4	0.921	0.243	0.057	0.268	0.338	0.294	2.123
N2O	0.689	0.002	0.001	0.003	0.003	0.003	0.700
CO2	1,031	166	43	195	261	224	1,919
Total GHG	1,259	172	44	203	270	232	2,181
Total GHG Dry Mill (g/mmbtu)	4,464	611	156	718	958	822	7,730
Total GHG Dry Mill (g/MJ)	4.23	0.58	0.15	0.68	0.91	0.78	7.33

Similar to Table 2.05 in CARB Corn Ethanol Report

Table 28. Inputs and Calculated Emissions for Soil N2O from Sorghum Cultivation	
Component	Value
Fertilizer N input (g/bu)	424.8
Above and Below Biomass (g/bu)	141.7
Total (g/bu)	566.5
Percent conversion to N2O-N	1.325%
N2O formed/N2O-N (g/g)	1.57
N2O Emissions (g/bu)	11.79
GHG Emissions (gCO2e/mmBtu)	12,458
GHG Emissions (gCO2e/MJ)	11.81

Similar to Table 2.06 in CARB Corn Ethanol Report

Table 29. Chemical Input Emissions (g/MJ)	
Component	Emissions
Fertilizer	5.64
Herbicide	0.91
Pesticide	0.78
Soil N2O	11.81
CO2 from CaCO3	0.45
CO2 from Urea	0.47
VOC and CO	0.05
Total	20.10

Similar to Table 2.07 in CARB Corn Ethanol Report

7.3 Ethanol Production Emissions

Ethanol production emissions were obtained using the GREET model for each year, and averaging the results, which are shown in Table 30. Most of the distillers' grains provided by the plant are wet (at 65% moisture), but a small amount are dry, so the energy included in Table 30 includes this energy for the DDGs. It is not possible for us to separate the energy for wet and dry DGs in this plant, we will assume that the plant produces entirely wet DGs. The 2008 and 2009 individual year results are shown in Appendix 5.

Table 30. Calculated CO2 Emissions (g/gal Anhydrous) for Dry Mill Ethanol Production

Fuel/Source	CO2 in g/gal	CO2 in g/mmBtu
Natural Gas		
Large Industrial Boiler	665	
Small Industrial Boiler	664	
WTT NG	120	
Total	1,449	18,991
Electricity		
As Feedstock	13	
As Fuel	383	
Total	395	5,182
VOC	2.467	101
CO	1.140	23
CH4	3.501	1,147
N2O	0.015	57
Total GHGs (gCO2e/mmBtu)		25,501
Total GHGs (gCO2e/MJ)		24.17

Similar to Table 4.05 in CARB Corn Ethanol Report

We are unable to estimate utilities for the sorghum and wheat slurry streams separately, since they are both being used continuously. However, we can examine the relationship between the fraction of wheat slurry in the total feedstock and the utility emissions. Table 9 shows that in 2008 and 2009, there was a difference in the wheat slurry fraction. This is shown further in Table 31, where we estimated the ethanol production emissions for both years.

Table 31. Ethanol Production Emissions for 2008 and 2009		
	2008	2009
Sorghum + corn input (million bu)	[redacted]	[redacted]
Wheat slurry input (million bu)	[redacted]	[redacted]
Total input (million bu)	[redacted]	[redacted]
Wheat slurry fraction of input	[redacted]	[redacted]
Ethanol production emissions estimated with GREET (g/MJ)	[redacted]	[redacted]

[redacted] The emissions in 2009 are slightly lower than in 2008.

7.4 Co-product Emissions

Our investigation into the type of feed that sorghum DDGs replaces indicates that these DDGs replace mainly corn. To estimate co-product credits, we utilize the dry DG output of the plant (per gal) from Table 10 with the GREET coproduct model for corn. The results for 2008 and 2009 (average) are shown in Table 32. Individual year results are shown in Appendix 5.

Table 32. Russell Co-Product Emission Credits (average of 2008-2009)	
	Dry Mill
Pollutant	Displaced Product - Feed Corn
VOC	-0.595
CO	-5.366
CH4	-0.643
N2O	-1.478
CO2	-534
GHG (gCO2e/mmBtu anhydrous)	-13,111
GHG (g/CO2e/MJ anhydrous)	-12.43

7.5 Summary of Direct Emission Results

The summary of results for the Russell plant is shown in Table 33. In this table, we have also added 0.8 g/MJ for denaturant. Emissions are lower for the Russell plant than for a corn dry mill plant with 100% dry DGs, due to predominantly wet DGs being generated at Russell, and also the use of the waste starch slurry stream for producing some ethanol.

Table 33. GHG Direct Lifecycle Emissions for the Russell Plant
(Equivalent to CARB Report Table B)

Well-to-Tank Ethanol Cycle Components	Russell Sorghum + Wheat Stream GHG (gCO2e/MJ) (avg of 2008-2009)	Corn Dry Mill GHG (gCO2e/MJ), dry DGs
Farming	3.80	5.65
Ag Chemical Production	20.10	30.20
Transport	1.62	2.22
Ethanol Production	24.17	38.30
Ethanol T&D	2.70	2.70
Co-Products	-12.43	-11.51
Subtotal	39.95	67.56
Denaturant	0.80	0.80
Total	40.75	68.36

Farming emissions are somewhat lower than for a corn for the reasons mentioned in the previous section. Agriculture chemical emissions are also lower. Transport emissions of the feedstock are lower because there are no transport emissions for the wheat slurry feedstock, which increases ethanol output. Ethanol production emissions are lower than for the corn plant because the vast majority of the distillers' grains are not dried. The co-product credit is higher than the ARB model indicates, primarily because the ARB corn model assumes 5.34 lbs of dry DGs/gal of ethanol, where the output of the Russell plant is 5.7 lbs/gal over 2008-2009 (see Table 10).

7.6 Land Use

AIR has not performed an analysis of land use emissions for sorghum. However, CARB has stated an intention to use the same land use emissions for sorghum as for corn, which is 30 g/MJ. AIR may do further work on land use emissions from sorghum used for ethanol.

For the time being, we will assume that sorghum's land use emissions are 30 g/MJ. The Russell plant utilizes both sorghum and wheat slurry as a feedstock. The sorghum should have the 30 g/MJ applied to it, but the land use emissions of the wheat slurry stream are zero, since it is a waste stream. Therefore, the 30 g/MJ must be adjusted downward.

We can adjust the land use emissions with the ratio of total bushels input to the plant that are due to sorghum. For example, in the 2008-2009 period, the fraction of total bushels due to sorghum (or sorghum + corn) was 76%, but it ranged from 72% to 80%. Thus, the

average land use emissions for this period ranges from 21.6 to 24.0, with an average of 22.8.

7.7 Trend of Total CI with Sorghum Fraction

As we have observed, the higher the sorghum fraction, the higher the overall CI, due to farming, agriculture, and land use emissions (or, the higher the slurry fraction, the lower the CI). Thus, some lower limit of slurry fraction needs to be placed on the CI estimate.

As discussed earlier, the Russell plant utilizes a waste wheat slurry stream in addition to sorghum. There is some year-to-year variation in the fraction of the waste wheat slurry stream. As shown in Table 9, over the period from 2008-2009, this fraction varied between 20% and 26%, but currently, it is about 33%.

Table 34 shows the variation in emissions between 2008 and 2009, using the individual year results from GREET modeling for the plant. Figure 1 shows this relationship (Figure 1 also includes the land use emissions).

Table 34. Russell Emissions, 2008 and 2009

Component	2008	2009
Slurry Fraction	[redacted]	[redacted]
Farming	[redacted]	[redacted]
Ag Chemicals	[redacted]	[redacted]
Sorghum Transport	[redacted]	[redacted]
Production	[redacted]	[redacted]
Ethanol T&D	[redacted]	[redacted]
Co-Products	[redacted]	[redacted]
Denaturant	[redacted]	[redacted]
Land Use	[redacted]	[redacted]
Total	[redacted]	[redacted]

[redacted]

The plant is typically operated between 20 and 30%. However, it is possible that the plant could be operated between 15% and 35%. Using the relationship in Figure 1, which was developed for these two years where the slurry fraction varied between 20% and 28%, we developed the CI for the plant at 15%, 20%, 25%, 30%, and 35%. These values are shown in Table 35.

Table 35. CI of Russell at Different Wheat Slurry Fractions

Slurry Fraction	CI (g CO2 eq/MJ)
15%	69.36
20%	66.16
25%	62.96
30%	59.76
35%	56.56

7.8 Modified and Dry Distillers Grains

The Russell plant may produce both dry and modified distillers grains in the future. The dry distillers grains would be produced with a moisture content of 12%, and the modified product would be provided with a moisture content of 50%. These products would be produced by operating the dryer for a longer period of time, and this would consume more natural gas, causing the plant's carbon intensity to be higher. Ideally, if we had energy values for when the plant was being operated exclusively to produce dry and modified distillers grains, the impact could be developed from these plant energy values. However, this has not been done at the plant, so we do not have these values, and have to develop an alternative method of making these estimates. Our proposal is to develop the difference in carbon intensity from the CARB Corn Ethanol values for wet and dry DGs, and add these to the value we have for the Hereford plant as a wet DGS plant.

7.8.1 Dry DGs from CARB's Corn Ethanol Values

Table 36 shows CARB's corn ethanol values for a Midwest, NG corn ethanol plant with both wet and dry DGs. [1] When dry DGs are provided, the direct CI is 8.3 g/MJ higher than when provided in the wet condition. For Hereford, we propose to add 8.3 g/MJ to the CI of the plant for estimating the plant emissions for dry DGs.

Table 36. CI Values for CARB Corn Ethanol NG Plant in the Midwest

DGs	CI (g/MJ), without LUC
Dry	68.4
Wet	60.1
Difference, Dry-Wet	8.3

7.8.2 Modified Distillers Grains

Dry distillers grains typically have a moister content of 12%, while wet distillers grains provided at the Russell plant have a moisture content of 65%. White intends to offer a modified distillers grains product with a moisture content of 50%. This product would be produced from dryers that are fueled with natural gas. The carbon intensity of the modified product can be interpolated from the moisture content of the modified product and the CARB carbon intensities of the wet and dry distillers grains shown in Table 37. We propose to add 2.3 g/MJ to the wet DG carbon intensity to estimate the CI of the plant operated producing modified DGS.

Table 37. CI Values for CARB Corn Ethanol NG Plant in the Midwest

DGs	CI (g/MJ), without LUC
Dry (12%)	68.4
Modified (50%)	62.4
Wet (65%)	60.1

7.9 Overall Emissions at Different Wheat Slurry Fractions

Table 38 shows the estimated CI of the plant at a number of different wheat slurry fractions: 10%, 15%, 20%, 25%, 30%, and 35%. We also show the values with dry and modified distiller's grains.

Table 38. Carbon Intensities of Russell Plant at Different Wheat Slurry Fractions (includes land use effect)

	Wheat Slurry Fraction				
	15%	20%	25%	30%	35%
Wet DGs	69.36	66.16	62.96	59.76	56.56
Dry DGs	77.66	74.46	71.26	68.06	64.86
Modified DGs	71.66	68.46	65.26	62.06	58.86

References

1. "Detailed California-Modified GREET Pathway for Corn Ethanol", February 27, 2009, Version 2.1.

2. National Agricultural Statistics Service, U.S. Department of Agriculture, http://quickstats.nass.usda.gov/.

3. Economic Research Service, U.S. Department of Agriculture, February 1997, FBE97-1, contacts: Nora Brooks and Robert McElroy

4. "Renewable Fuel Standard (RFS2) Regulatory Impact Analysis", EPA-420-R-10-006, February 2010, Figures 2.4-3, 2.4-4, 2.4-5, and 2.4-6.

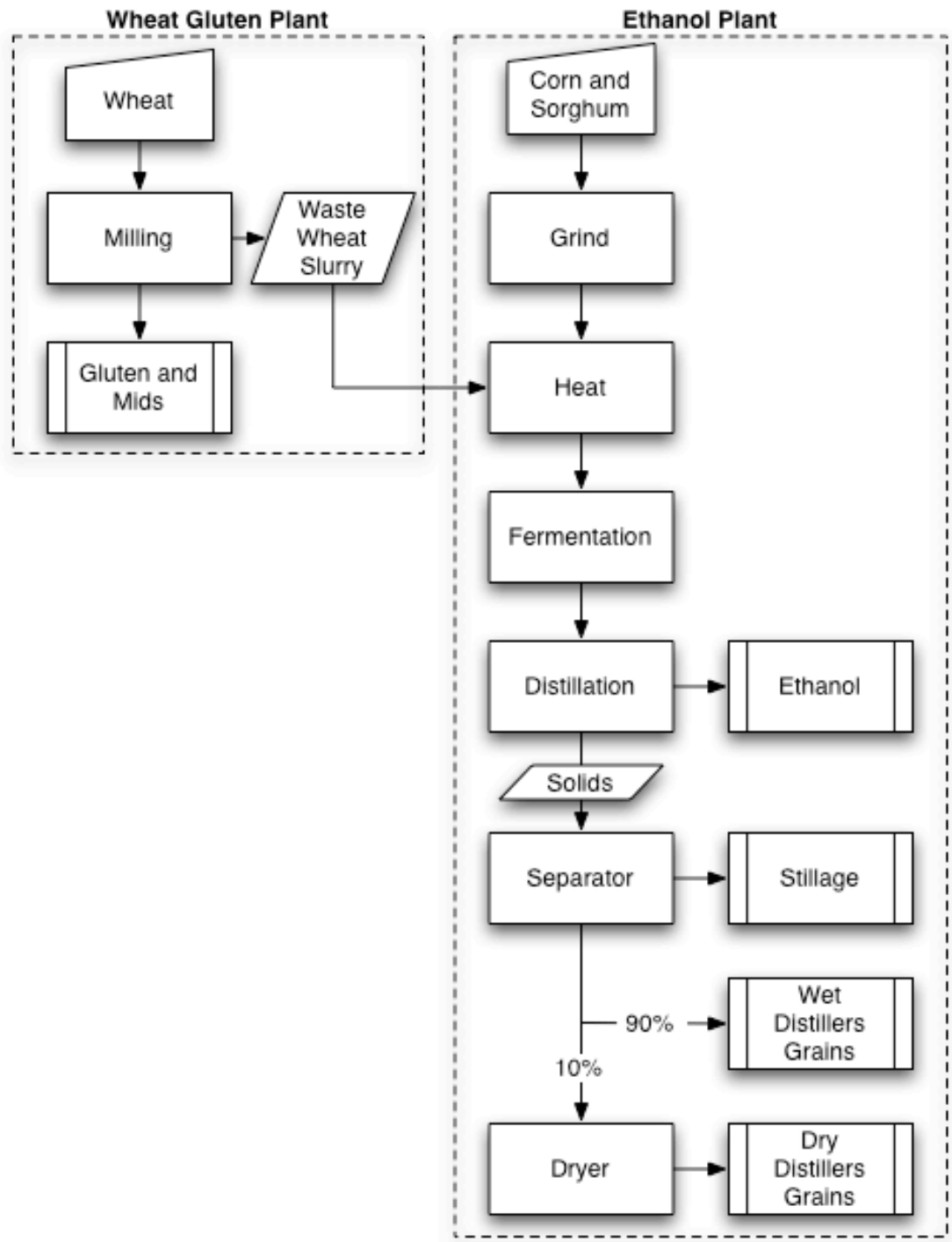
5. Personal communication with and data file from Dr. Richard Nelson, Director and Department Head, Engineering Extension Programs, KSU (Bio-Based Energy Analysis Group), obtained 13 April 2010.

6. O'Brien, et al, "Grain Sorghum Cost-Return Budget to North Central Kansas, Department of Agricultural Economics, KSU, Report MF-2159, December 2009.

7. Economic Research Service, U.S. Department of Agriculture, http://www.ers.usda.gov/data/arms/cropoverview.htm.

Appendix 1

Flow Diagram for the Russell Plant



Russell Combustion Equipment

[redacted]

[redacted]

[redacted]

[redacted]

Appendix 2

Further Details on Sorghum Yields Around Russell

Kansas agricultural districts are shown in the figure below. District 50 is the Central (C) district. Table 2-1 shows the counties that provide sorghum to the Russell. Plant Table 2-2 shows the yields for these counties.

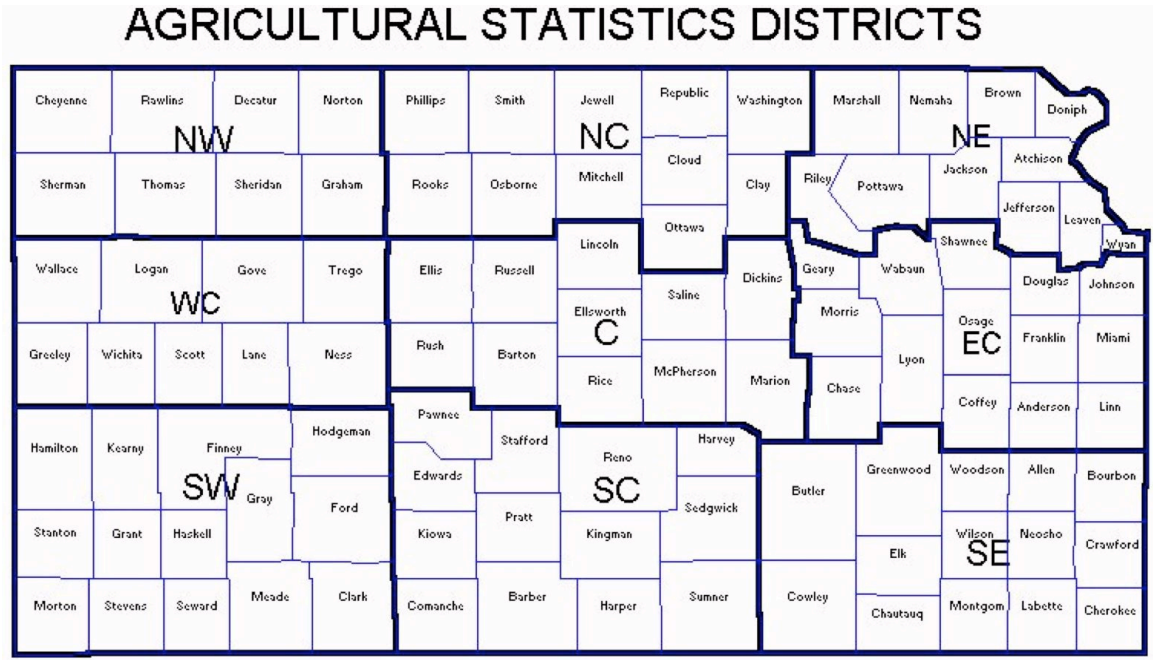


Table 2-1. White Energy Russell Plant Sorghum Grain Procurement	
County	District
Ellis	Central (C)
Ellsworth	Central (C)
Russell	Central (C)
Jewell	North Central (NC)
Mitchell	North Central (NC)
Osborne	North Central (NC)
Rooks	North Central (NC)
Smith	North Central (NC)

Table 2-2. Sorghum Yield by Kansas Region (bushels/acre)			
Year	Central District	North Central District	Average of 8 Procurement Counties
2004	93	87	81.1
2005	71	96	85.1
2006	56	76	65.6
2007	85	93	93.4
2008	91	108	110.2
2009	92	101	96.9
Average	81.3	93.5	88.7

Appendix 3

Letter from Russell City Regarding Electricity Mix

CITY OF Russell

P.O. Box 112
133 W. 8th
Russell, KS 67665-0112
Phone: (785) 483-6311
Fax: (785) 483-4397

December 8, 2010

Dave Harry, Controller
White Energy
1030 E. 15th
Russell, KS 67665

The electric sources for the Russell municipal electrical system for the years 2008 and 2009 are shown below.

Residual Oil	0.0%
Natural gas	27.2%
Coal	49.2%
Nuclear	0.0%
Biomass	0.0%
Renewable (hydro, Wind, and geothermal)	23.6%
Total	100.0%

Please call if you have any questions, or need additional information.

Sincerely,

Sheldon Hamilton

Sheldon L. Hamilton
Finance Director, Treasurer, Clerk

www.russellcity.org email: russellcity@russellcity.org

Appendix 4

Modifications in GREET for Russell

Modifications Made to CA-GREET Model for Russell Sorghum Analysis			
Worksheet	Type	Cell(s)	Purpose
Ag_Inputs	Insertion	J91:Q126	Insert Sorghum and Wheat Calculations to "Herbicides: Average for Crop Type" in Section 4) Summary of Energy Use and Emissions of Agricultural Chemicals: per gram
Ag_Inputs	Addition	L277:P301	Add "Sorghum Farming" calculations to Section 5.4) Summary of Energy Use and Emissions of Farming Machinery
Ag_Inputs	Insertion	Y91:Z126	Insert Sorghum and Wheat Calculations to "Insecticides: Average for Crop Type" in Section 4) Summary of Energy Use and Emissions of Agricultural Chemicals: per gram
EtOH	Insertion	A92:E125	Insert input and calculation Section "1.2d) Key Assumptions Regarding Sorghum-Ethanol"
EtOH	Addition	AE133:AJ158	Add "Calculations of Co-Product Credits for Sorghum Ethanol" to Section 1.3) The Types of Electricity Displaced by Co-Produced Electricity in Biomass-based EtOH Plants for Export
EtOH	Addition	AO230:AP254	Add complete "Dry Milling Sorghum Ethanol " calculations and summary to Section 4) Summary of Energy Consumption and Emissions: Btu or Grams per mmBtu of Fuel Throughput at Each Stage; Subsection 4.1) Energy Consumption and Total Emissions
EtOH	Addition	AQ230:AR254	Add complete "Wet Milling Sorghum Ethanol " calculations and summary to Section 4) Summary of Energy Consumption and Emissions: Btu or Grams per mmBtu of Fuel Throughput at Each Stage; Subsection 4.1) Energy Consumption and Total Emissions

EtOH	Addition	AS230:AT254	Add complete "Sorghum Ethanol: Combined Dry and Wet Milling Ethanol " calculations and summary to Section 4) Summary of Energy Consumption and Emissions: Btu or Grams per mmBtu of Fuel Throughput at Each Stage; Subsection 4.1) Energy Consumption and Total Emissions
EtOH	Addition	CY177:DG266	Add complete "Sorghum Farming: calculations and display to Section 3) Calculations of Energy Consumption and Emissions for Each Stage
EtOH	Addition	DH177:DK266	Add complete "Sorghum Ethanol Production" calculations and display to Section 3) Calculations of Energy Consumption and Emissions for Each Stage
EtOH	Addition	DL177:DO266	Add complete "Co-Product Credits of Sorghum Ethanol: Market Value Method" calculations and display to Section 3) Calculations of Energy Consumption and Emissions for Each Stage
EtOH	Addition	DP177:DV266	Add complete "Co-Product Credits of Sorghum Ethanol: Displacement Method" calculations and display to Section 3) Calculations of Energy Consumption and Emissions for Each Stage
EtOH	Addition	DW177:DX266	Add complete "Surghum Ethanol and Cellulosic Ethanol T&D" calculations and display to Section 3) Calculations of Energy Consumption and Emissions for Each Stage
EtOH	Addition	H10:I11	Add Sorghum and Wheat "N content of above and below ground biomass: grams/bushel for corn, grams/ton for cellulosic biomass, and grams/tonne for sugar cane" to Section 1.1) Feedstock Farming
EtOH	Addition	H13:I14	Add Sorghum and Wheat "N2O Emissions: N in N2O as % of N in N fertilizer and biomass" to Section 1.1) Feedstock Farming

EtOH	Addition	I16:J22	Add Sorghum and Wheat "Farming Energy Use and Fertilizer Use" to Section 1.1) Feedstock Farming
EtOH	Addition	I24:J25	Add Sorghum and Wheat "CO2 Emissions from Land Use Change" to Section 1.1) Feedstock Farming
EtOH	Addition	I5:J6	Add Sorghum and Wheat "Shares of Feedstocks for Ethanol Production" to Section 1) Scenario Control and Key Input Parameters
EtOH	Addition	P161:S174	Add Sorghum and Wheat calculations to Section 2) Shares of Combustion Processes for Each Stage
Fuel_Prod_TS	Addition	AA285:AC293	Add data table to Shares of Ethanol Production Section for "Share of Sorghum EtOH to Total EtOH Production"
Fuel_Prod_TS	Addition	AE285:AG293	Add placeholder data table to Shares of Ethanol Production Section for "Share of Wheat EtOH to Total EtOH Production"
Fuel_Prod_TS	Addition	AI285:AK293	Add data table to Shares of Ethanol Production Section for "Share of Dry Mill Sorghum EtOH Production Between Dry and Wet Sorghum EtOH Production"
Fuel_Prod_TS	Addition	AM285:AO293	Add placeholder data table to Shares of Ethanol Production Section for "Share of Dry Mill Wheat EtOH Production Between Dry and Wet Sorghum EtOH Production"
Fuel_Prod_TS	Addition	CU269:CW279	Add data table to Ethanol Production Section for "EtOH Yield of Sorghum EtOH Plant: Dry Mill, gal/bushel"
Fuel_Prod_TS	Addition	CY269:DA279	Add data table to Ethanol Production Section for "EtOH Yield of Sorghum EtOH Plant: Wet Mill, gal/bushel"
Fuel_Prod_TS	Addition	DC255:DE265	Add data table to Corn and Biomass Farming Section for "Sorghum Farming Energy Use: Btu/bushel of Sorghum"
Fuel_Prod_TS	Addition	DC269:DE279	Add data table to Ethanol Production Section for "Sorghum EtOH Plant Energy Use: Dry Mill, Btu/gal"

Fuel_Prod_TS	Addition	DG255:DI265	Add data table to Corn and Biomass Farming Section for "N Fertilizer Use for Sorghum Farming: N grams/bushel"
Fuel_Prod_TS	Addition	DG269:DI279	Add data table to Ethanol Production Section for "Sorghum EtOH Plant Energy Use: Wet Mill, Btu/gal"
Fuel_Prod_TS	Addition	DK255:DM265	Add data table to Corn and Biomass Farming Section for "P2O5 Fertilizer Use for Sorghum Farming: P2O5 grams/bushel"
Fuel_Prod_TS	Addition	DK269:DM279	Add data table to Ethanol Production Section for “Co-Products Dry Mater Yield, pounds/gallon”
Fuel_Prod_TS	Addition	DO271:DQ279	Add data table to Ethanol Production Section for "Share of Coal in Total Process Fuels of Sorghum Ethanol Plant: Dry Milling"
Fuel_Prod_TS	Addition	DO255:DQ265	Add data table to Corn and Biomass Farming Section for "K2O Fertilizer Use for Sorghum Farming: K2O grams/bushel"
Fuel_Prod_TS	Addition	DS271:DU279	Add data table to Ethanol Production Section for "Share of Coal in Total Process Fuels of Sorghum Ethanol Plant: Wet Milling"
Fuel_Prod_TS	Addition	DS255:DU265	Add data table to Corn and Biomass Farming Section for "CaCO3 Fertilizer Use for Sorghum Farming: CaCO3 grams/bushel"
Fuel_Prod_TS	Addition	DW257:DY265	Add data table to Corn and Biomass Farming Section for "Herbicide Use for Sorghum Farming: grams/bushel"
Fuel_Prod_TS	Addition	EA255:EC265	Add data table to Corn and Biomass Farming Section for "Insecticide Use for Sorghum Farming: grams/bushel"
Fuel_Prod_TS	Addition	EE255:EG265	Add placeholder data table to Corn and Biomass Farming Section for "Wheat Farming Energy Use: Btu/bushel of Wheat"
Fuel_Prod_TS	Addition	EI255:EK265	Add placeholder data table to Corn and Biomass Farming Section for "N Fertilizer Use for Wheat Farming: N grams/bushel"

Fuel_Prod_TS	Addition	EM255:EO265	Add placeholder data table to Corn and Biomass Farming Section for "P2O5 Fertilizer Use for Wheat Farming: P2O5 grams/bushel"
Fuel_Prod_TS	Addition	EQ255:ES265	Add placeholder data table to Corn and Biomass Farming Section for "K2O Fertilizer Use for Wheat Farming: K2O grams/bushel"
Fuel_Prod_TS	Addition	EU257:EW265	Add placeholder data table to Corn and Biomass Farming Section for "CaCO3 Fertilizer Use for Wheat Farming: CaCO3 grams/bushel"
Fuel_Prod_TS	Addition	EY257:FA265	Add placeholder data table to Corn and Biomass Farming Section for "Herbicide Use for Wheat Farming: grams/bushel"
Fuel_Prod_TS	Addition	FC255:FE265	Add placeholder data table to Corn and Biomass Farming Section for "Insecticide Use for Wheat Farming: grams/bushel"
Fuel_Prod_TS	Addition	FG255:FI265	Add data table to Corn and Biomass Farming Section for "CO2 Emissions from Landuse Change: Sorghum Farm, grams/bushel"
Fuel_Prod_TS	Addition	FK255:FM265	Add data table to Corn and Biomass Farming Section for "CO2 Emissions from Landuse Change: Wheat Farm, grams/bushel"
Fuel_Prod_TS	Addition	FO257:FQ265	Add data table to Corn and Biomass Farming Section for "Sorghum Yield, bu/harvest acre"
Fuel_Prod_TS	Addition	FS257:FU265	Add placeholder data table to Corn and Biomass Farming Section for "Wheat Yield, bu/harvest acre"
Inputs	Insertion	A272:D313	Insert Section 7.9) "Key Assumptions for Simulating Sorghum-Based Ethanol Production" (includes Sections 7.9.a, 7.9.b, 7.9.c, 7.9.c.1, 7.9.c.2, and 7.9.c.3). All appropriate data transfers from other worksheets and calculations also included.
Inputs	Addition	F206:G207	Add Sorghum and Wheat inputs for Section 7.4a) "N content of above and below ground biomass…"

Inputs	Addition	F209:G210	Add Sorghum and Wheat inputs for Section 7.4b) "N2O emissions…"
Inputs	Addition	I184:J185	Add Sorghum and Wheat inputs for Section 7.1) "Share of Each Beedstock"
Inputs	Addition	I187:J197	Add Sorghum and Wheat inputs for Section 7.2) "Farming Energy Use and Fertilizer Use" Section
Inputs	Addition	I200:J201	Add Sorghum and Wheat inputs for Section 7.3) "CO2 Emissions from Potential Land Use Changes of Farming: grams/bushel for corn, grams/dry ton for cellulosic biomass, and grams/tonne for sugar cane"
Regional LT	Modification	C2	Add "Russell" to Pull Down Menu
Regional LT	Addition	M6:M195	Include Russell Electrical Mix Parameters
T&D	Addition	DQ135:DR165	Add Sorghum "Farm to Collection Stack" and "Stack to Ethanol Plant" calculations to Section 10
T&D	Addition	DS135:DT165	Add Wheat "Farm to Collection Stack" and "Stack to Ethanol Plant" calculation to Section 10
T&D	Addition	II90:IL132	Add Sorghum "Truck, Barge, Rail, Truck" calculations to Section 9
T&D	Addition	IM90:IP132	Add Wheat "Truck, Barge, Rail, Truck" calculations to Section 9
T&D Flowcharts	Addition	B1519:AE1531	Add Sorghum transportation and distribution inputs, unnecessary graphics omitted
T&D Flowcharts	Addition	B1534:AE1546	Add Wheat transportation and distribution inputs, unnecessary graphics omitted
Urban Shares	Insertion	B80:H81	Add Sorghum and Wheat Inputs to Section 3: "Urban Shares of Transportation Mode Activities"
Urban Shares	Addition	I151:J152	Add Sorghum and Wheat Inputs for Section 7: "Urban Shares of Ethanol Activities; Farming"
Urban Shares	Addition	O153:P154	Add Sorghum Inputs for Section 7: "Urban Shares of Ethanol Activities; Ethanol Production"

Appendix 5
Tables for Individual Years

2008 Russell Tables

Table 1.01 Primary Energy Inputs by Fuel/Energy Input Type for Sorghum Farm Operations, Russell, 2008

Fuel Type	Fuel Share	Primary Energy Input (Btu/bushel)
Residual Oil	0.00%	0
Diesel Fuel	62.97%	7,442
Gasoline	36.97%	4,369
Natural Gas	0.00%	0
Coal	0.00%	0
Liquefied Petroleum Gas	0.00%	0
Electricity	0.05%	6
Sorghum Cultivation (Btu/bushel)		**11,817**

Table 1.09 GHG Emissions from Sorghum Farming, With Loss Factor, Russell, 2008

Sorghum Ethanol Prodution		Dry Mill
Emissions Species	Emissions (g/bu)	GHG (gCO2e/mmBtu)
VOC	3.28	37.79
CO	74.38	432.54
CH4	1.38	127.50
N2O	0.02	16.90
CO2	963.78	3,566.67
Total GHG (gCO2e/mmBtu)		4,181.40
Total GHG (gCO2e/MJ)		**3.96**

Table 2.05 Calculated GHG Emissions from Production of Agricultrual Chemicals, With Loss Factor, Russell, 2008

GHG Type	Nitrogen	P2O5	K2O	CaCO3	Herbicide	Insecticide	Total
	g/bu						
CH4	0.921	0.243	0.057	0.268	0.338	0.294	2.123
N2O	0.689	0.002	0.001	0.003	0.003	0.003	0.700
CO2	1,031	166	43	195	261	224	1,919
Total GHG	1,259	172	44	203	270	232	2,181
Total GHG Dry Mill (g/mmbtu)	4,661	638	163	750	1,000	858	8,070
Total GHG Dry Mill (g/MJ)	**4.42**	**0.60**	**0.15**	**0.71**	**0.95**	**0.81**	**7.65**

Table 2.06 Inputs and Calculated Emissions for Soil N2O from Sorghum Cultivation, With Loss Factor, Russell, 2008

Sorghum Crop	Fertilizer N input (g/bu)	Above and Below Biomass (g/bu)	Total (g/bu)	Percent Conversion to N2O-N	N2O formed/ N2O-N (g/g)	N Converted (g/bu)	N2O Emissions (g/bu)	GHG Emissions (gCO2e/mmBtu)	GHG Emissions (gCO2e/MJ)
Dry Mill	424.8	141.7	566.5	1.325%	1.57	7.44	11.79	13,007	12.33

Table 2.07 Total GHG Emissions for Agricultrual Chemical Use for Sorghum Ethanol (All in gCO2e/MJ), With Loss Factor, Russell, 2008

Ethanol	Fertilizers	Herbicide	Pesticide	Soil N2O	CO2 from CaCO3	CO2 from Urea	VOCs and CO	Total
Dry Mill	5.89	0.95	0.81	12.33	0.47	0.49	0.05	20.99

Table B. GHG Emissions for Dry Mill Sorghum Ethanol, With Loss Factor, Russell, 2008

Sorghum Ethanol Fuel Cycle Components	Dry Mill
Well-to-Tank	GHG (gCO2/MJ)
Sorghum Farming	3.96
Ag Chemical Production	20.99
Sorghum Transport	1.69
Ethanol Production	24.30
Ethanol T&D	2.69
Co-Products	-12.28
Total	**41.35**

Table 4.05 Calculated CO2 Emissions (g/gal Anhydrous) for Dry Mill Ethanol Production, Russell, 2008

	CO2 in g/gal	CO2 in g/mmBtu
Natural Gas		
Large Industrial Boiler	660	
Small Industrial Boiler	659	
WTT NG	119	
Total	1,438	18,850
Electricity		
As Feedstock	13	
As Fuel	403	
Total	417	5,463
VOC	2.467	101
CO	1.154	24
CH4	3.508	1,149
N2O	0.015	58
Total GHGs (gCO2e/mmBtu)		25,646
Total GHGs (gCO2e/MJ)		**24.30**

Table 6.05 Dry Mill Co-Product Emission Credits, With Loss Factor, Russell, 2008

Displaced Product	Dry Mill Feed Sorghum
VOC	-0.588
CO	-5.303
CH4	-0.635
N2O	-1.460
CO2	-528
GHGs (g/gal anhydrous)	0
GHG (gCO2e/mmBtu anhydrous)	-12,955
GHG (g/CO2e/MJ anhydrous)	**-12.28**

2009 Russell Tables

Table 1.01 Primary Energy Inputs by Fuel/Energy Input Type for Sorghum Farm Operations, Russell, 2009

Fuel Type	Fuel Share	Primary Energy Input (Btu/bushel)
Residual Oil	0.00%	0
Diesel Fuel	62.97%	7,442
Gasoline	36.97%	4,369
Natural Gas	0.00%	0
Coal	0.00%	0
Liquefied Petroleum Gas	0.00%	0
Electricity	0.05%	6
Sorghum Cultivation (Btu/bushel)		**11,817**

Table 1.09 GHG Emissions from Sorghum Farming, With Loss Factor, Russell, 2009

Sorghum Ethanol Prodution		Dry Mill
Emissions Species	Emissions (g/bu)	GHG (gCO2e/mmBtu)
VOC	3.28	34.73
CO	74.38	397.52
CH4	1.38	117.18
N2O	0.02	15.53
CO2	963.78	3,277.86
Total GHG (gCO2e/mmBtu)		3,842.81
Total GHG (gCO2e/MJ)		**3.64**

Table 2.05 Calculated GHG Emissions from Production of Agricultrual Chemicals, With Loss Factor, Russell, 2009

GHG Type	Nitrogen	P2O5	K2O	CaCO3	Herbicide	Insecticide	Total
	g/bu						
CH4	0.921	0.243	0.057	0.268	0.338	0.294	2.123
N2O	0.689	0.002	0.001	0.003	0.003	0.003	0.700
CO2	1,031	166	43	195	261	224	1,919
Total GHG	1,259	172	44	203	270	232	2,181
Total GHG Dry Mill (g/mmbtu)	4,283	587	150	689	919	788	7,417
Total GHG Dry Mill (g/MJ)	**4.06**	**0.56**	**0.14**	**0.65**	**0.87**	**0.75**	**7.03**

Table 2.06 Inputs and Calculated Emissions for Soil N2O from Sorghum Cultivation, With Loss Factor, Russell, 2009

Sorghum Crop	Fertilizer N input (g/bu)	Above and Below Biomass (g/bu)	Total (g/bu)	Percent Conversion to N2O-N	N2O formed/N2O-N (g/g)	N Converted (g/bu)	N2O Emissions (g/bu)	GHG Emissions (gCO2e/mmBtu)	GHG Emissions (gCO2e/MJ)
(for Dry Mill)	424.8	141.7	566.5	1.325%	1.57	7.44	11.79	11,954	11.33

Table 2.07 Total GHG Emissions for Agricultrual Chemical Use for Sorghum Ethanol (All in gCO2e/MJ), With Loss Factor, Russell, 2009

Ethanol	Fertilizers	Herbicide	Pesticide	Soil N2O	CO2 from CaCO3	CO2 from Urea	VOCs and CO	Total
Dry Mill	5.41	0.87	0.75	11.33	0.43	0.45	0.04	19.29

Table B. GHG Emissions for Dry Mill Sorghum Ethanol, With Loss Factor, Russell, 2009

Sorghum Ethanol Fuel Cycle Components	Dry Mill
Well-to-Tank	GHG (gCO2/MJ)
Sorghum Farming	3.64
Ag Chemical Production	19.29
Sorghum Transport	1.55
Ethanol Production	24.03
Ethanol T&D	2.69
Co-Products	-12.57
Total	**38.63**

Table 4.05 Calculated CO2 Emissions (g/gal Anhydrous) for Dry Mill Ethanol Production, Russell, 2009

	CO2 in g/gal	CO2 in g/mmBtu
Natural Gas		
Large Industrial Boiler	670	
Small Industrial Boiler	669	
WTT NG	121	
Total	1,460	19,131
Electricity		
As Feedstock	12	
As Fuel	362	
Total	374	4,900
VOC	2.466	101
CO	1.126	23
CH4	3.494	1,145
N2O	0.014	56
Total GHGs (gCO2e/mmBtu)		25,356
Total GHGs (gCO2e/MJ)		**24.03**

Table 6.05 Dry Mill Co-Product Emission Credits, With Loss Factor, Russell, 2009

Displaced Product	Dry Mill Feed Sorghum
VOC	-0.602
CO	-5.430
CH4	-0.650
N2O	-1.495
CO2	-540
GHG (gCO2e/mmBtu anhydrous)	-13,266
GHG (g/CO2e/MJ anhydrous)	**-12.57**