

**Detailed California-Modified GREET  
Pathways for Brazilian Sugarcane Ethanol:  
Average Brazilian Ethanol,  
With Mechanized Harvesting and  
Electricity Co-product Credit,  
With Electricity Co-product Credit**



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These comments will be compiled, reviewed, and posted to the LCFS website in a timely manner.

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# **SUMMARY**

### **CA-GREET Model Pathway for Brazil Sugarcane Ethanol**

A Well-To-Tank (WTT) life cycle analysis of a fuel (or blending component of fuel) pathway includes all steps from feedstock production to final finished product. Tank-To-Wheel (TTW) analysis includes actual combustion of fuel in a motor vehicle for motive power. Together WTT and TTW analysis are combined together to provide a total Well-To-Wheel (WTW) analysis.

A life cycle analysis model called the **G**reenhouse gases, **R**egulated **E**missions, and **E**nergy use in **T**ransportation (GREET)<sup>1</sup> developed by Argonne National Laboratory has been used to estimate the energy use and greenhouse gas (GHG) emissions associated with the entire pathway of producing ethanol from Brazilian sugarcane, transporting it via ocean tanker to a California port, distributed and finally used in a light-duty vehicle in California. The original Argonne model was modified to include California specific values and factors and this model, the CA-GREET model was published on the Low Carbon Fuel Standard website in February 2009 (<http://www.arb.ca.gov/fuels/lcfs/lcfs.htm>).

The original pathway document for sugarcane ethanol published in February 2009 was for baseline ethanol produced in Brazil, transported to and used in California. For this document, this original pathway termed 'baseline' pathway in this document is identical in all aspects to the pathway published in February 2009. However, the Board directed staff to analyze two additional scenarios for sugarcane ethanol to account for improved harvesting practices and the export of electricity from sugarcane ethanol plants in Brazil using energy from bagasse. Therefore, this document adds the two additional scenarios for ethanol from sugarcane in Brazil. These two are not to be considered average for all of Brazilian ethanol but specific cases when such practices are adopted in Brazil.

The first additional scenario (labeled Scenario 1) added here includes:

- a) mechanized harvesting of cane which is gradually replacing the traditional practice of burning straw before harvesting cane and;
- b) export of electricity (co-generated) from power plants that are capable of exporting additional energy beyond that required for processing in the plant (co-product credit).

The second additional scenario (labeled Scenario 2) added here is by considering only the export of electricity (co-product) from power plants capable of producing the additional electricity for export.

For the results presented in this document, none of the assumptions or values have been changed for the baseline pathway published in February 2009.

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<sup>1</sup> GREET Model: Argonne National Laboratory:  
[http://www.transportation.anl.gov/modeling\\_simulation/GREET/index.html](http://www.transportation.anl.gov/modeling_simulation/GREET/index.html)

Figure 1 below outlines the discrete components that comprise the baseline sugarcane ethanol pathway. The baseline pathway does not include impacts from the components corresponding to the dashed arrows which are for the two additional scenarios presented in this document.

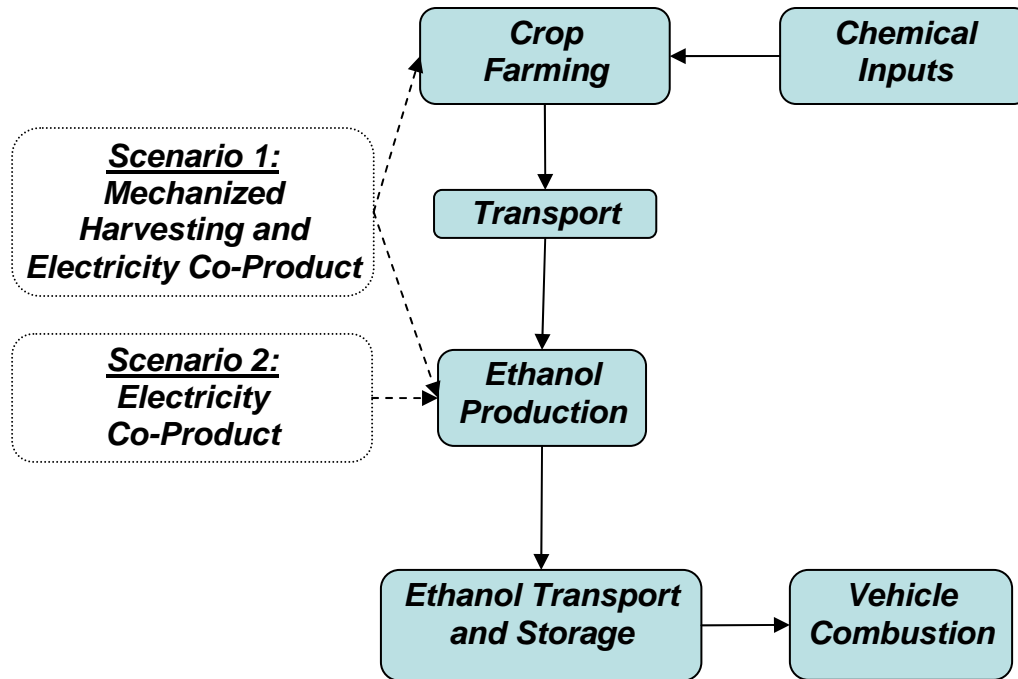


Figure 1. WTW Components for Sugarcane Ethanol Produced in Brazil and Transported for Use in CA

Several general descriptions and clarification of terminology used throughout this document are:

- CA-GREET employs a recursive methodology to calculate energy consumption and emissions. To calculate WTT energy and emissions, the values being calculated are often utilized in the calculation. For example, crude oil is used as a process fuel to recover crude oil. The total crude oil recovery energy consumption includes the direct crude oil consumption AND the energy associated with crude recovery (which is the value being calculated).
- Btu/mmBtu is the energy input necessary in Btu to produce one million Btu of a finished (or intermediate) product. This description is used consistently in CA-GREET for all energy calculations.
- gCO<sub>2</sub>e/MJ provides the total greenhouse gas emissions on a CO<sub>2</sub> equivalent basis per unit of energy (MJ) for a given fuel. Methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O) are converted to a CO<sub>2</sub> equivalent basis using IPCC Global Warming Potential (GWP) values and included in the total.



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- CA-GREET assumes that VOC and CO are converted to CO<sub>2</sub> in the atmosphere and includes these pollutants in the total CO<sub>2</sub> value using ratios of the appropriate molecular weights. This method is also used by the IPCC.
- Process Efficiency for any step in CA-GREET is defined as:

$$\text{Efficiency} = \text{energy output} / (\text{energy output} + \text{energy consumed})$$

- Note that rounding of values has not been performed in several tables in this document. This is to allow stakeholders executing runs with the GREET model to compare actual output values from the CA-modified model with values in this document.

Table A provides a summary of the WTW GHG emissions for the baseline pathway and the two additional scenarios described in this document.

*Table A. Summary of Baseline Pathway and Two Additional Scenarios*

| <b>Pathway Description</b>   | <b>WTW GHG* Emissions (gCO<sub>2</sub>e/MJ)</b> |
|--|---|
| Baseline Pathway<br>Brazilian sugarcane using average production processes   | 27.40   |
| Scenario 1<br>Brazilian sugarcane with average production process, mechanized harvesting and electricity co-product credit | 12.20   |
| Scenario 2<br>Brazilian sugarcane with average production process and electricity co-product credit                        | 20.40   |

\*These values do not include contributions from Land Use Change. This analysis is available in the staff report titled "Proposed Regulation to Implement the Low Carbon Fuel Standard - Initial Statement of Reasons (ISOR)" from the website: [www.arb.ca.gov/fuels/lcfs/lcfs.htm](http://www.arb.ca.gov/fuels/lcfs/lcfs.htm).

Results provided in this section are for all the three pathways: baseline and the two additional scenarios. All the components and values of the baseline pathway are applicable to the two additional scenarios presented in this document. Only certain components that provide GHG credits to the baseline pathway form the additional components for scenarios 1 and 2.

Table B summarizes the fuel cycle energy inputs by stage (Btu/mmBtu) and Table C summarizes the major GHG emission categories and intensities (gCO<sub>2</sub>e/MJ) for the baseline pathway. This is same as the document published in February 2009 for the Brazilian sugarcane ethanol pathway (see Appendix A1 for further details on energy use and emissions). Figure 2 shows the percentage energy contributions from the various components of the baseline ethanol pathway. From an energy viewpoint, ethanol production (48.6%) and carbon in fuel (44.4%) components dominate the baseline

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sugarcane ethanol pathway. Figure 3 shows the GHG contributions from the various components of this pathway. From a GHG viewpoint, sugarcane farming impacts (37.2%) and production and use of agricultural chemicals (32.7%) components are the major contributors to the sugarcane ethanol pathway. Complete details of all energy inputs and GHG emissions for the baseline pathway are provided in Appendix A1. For the two additional scenarios provided in this document, details are provided in Appendix A2. A list of all input values is provided in Appendix B.

Note: Since all the ethanol is produced from sugarcane which consists of CO<sub>2</sub> fixed via photosynthesis, the tailpipe emissions from combustion of ethanol is considered to be zero. This is because the CO<sub>2</sub> release from combustion was actually removed from the atmosphere by the feedstock. The addition of denaturant, however, does lead to contributions to CO<sub>2</sub> during combustion which is proportional to the amount of denaturant added to anhydrous ethanol. This value is not shown below in Table C under TTW category since the values are shown for anhydrous ethanol. The discussion and calculations are presented in Appendix A1. Since the use of anhydrous ethanol as a stand alone fuel is not permitted in California, this document does not include tailpipe emissions of CH<sub>4</sub> and N<sub>2</sub>O. An accompanying document for CaRFG<sup>2</sup> (containing ethanol as an oxygenate in CARBOB) provides combined effects including tailpipe emissions of using reformulated gasoline in a light-duty vehicle.

*Table B. Summary of Energy Use for the Baseline Sugarcane Ethanol Pathway*

| <b>Sugarcane Ethanol Components</b> | <b>Energy Use (Btu/mmBtu) (Anhydrous)</b> | <b>% Energy Contribution</b> |
|-------------------------------------|---|------------------------------|
| Sugarcane Farming                   | 26,407                                    | 1.2%                         |
| Energy Inputs for Ag Chemicals      | 59,616                                    | 2.7%                         |
| Sugarcane Transportation            | 25,722                                    | 1.1%                         |
| Ethanol Production                  | 1,093,376                                 | 48.6%                        |
| Ethanol T&D                         | 44,442                                    | 2%                           |
| <b>Total Well-to-Tank</b>           | <b>1,249,563</b>                          | <b>55.6%</b>                 |
| Carbon in Fuel                      | 1,000,000                                 | 44.4%                        |
| <b>Total Tank-to-Wheel</b>          | <b>1,000,000</b>                          | <b>44.4%</b>                 |
| <b>Total Well-to-Wheel</b>          | <b>2,249,563</b>                          | <b>100%</b>                  |

<sup>2</sup> See this CaRFG document published 02/2009 by ARB: [http://www.arb.ca.gov/fuels/lcfs/022709lcfs\\_carfg.pdf](http://www.arb.ca.gov/fuels/lcfs/022709lcfs_carfg.pdf)

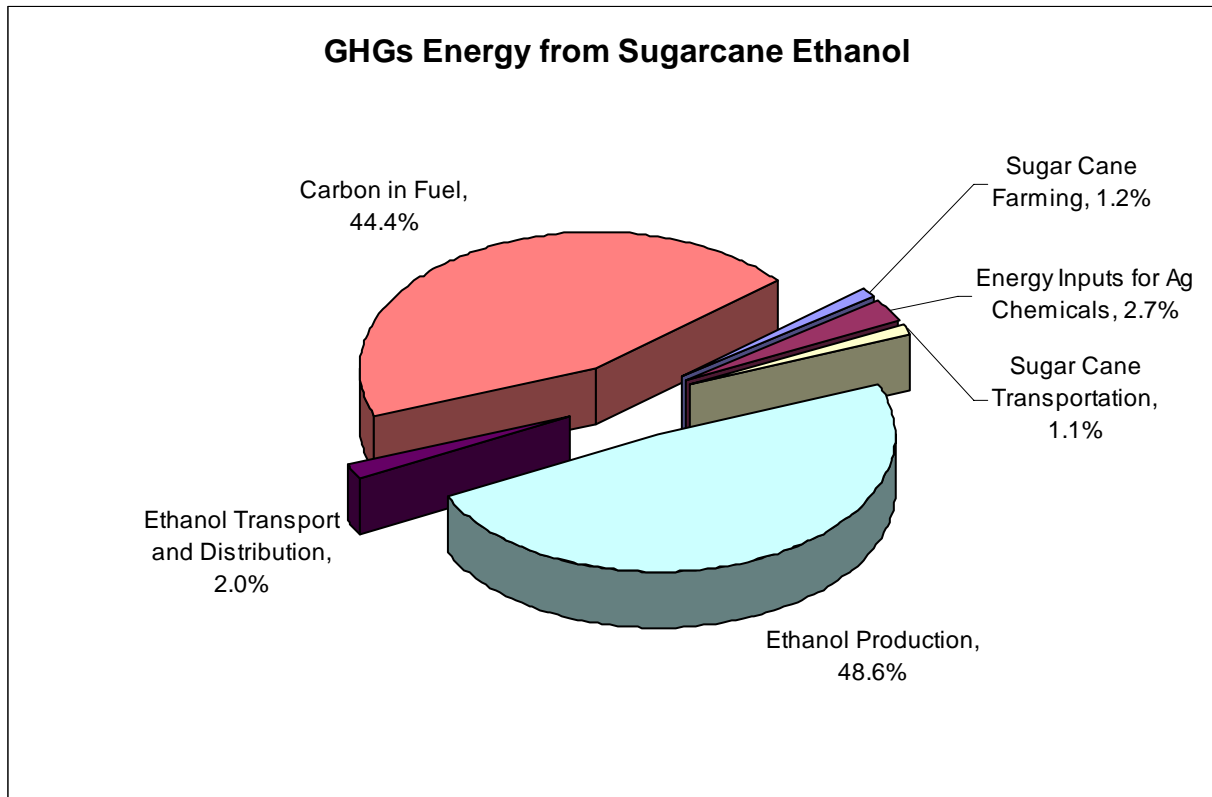


Figure 2. Percent Energy Contribution from WTW Analysis for Sugarcane Ethanol

Table C. GHG Emissions Summary for Sugarcane Ethanol

| Sugarcane Ethanol Components            | GHG Emissions (gCO <sub>2</sub> e/MJ) | % Emission Contribution |
|---|---------------------------------------|-------------------------|
| Sugarcane Farming (incl. straw burning) | 9.9                                   | 37.2%                   |
| Ag Chemicals Production and Use Impacts | 8.7                                   | 32.7%                   |
| Sugarcane Transportation                | 2.0                                   | 7.5%                    |
| Ethanol Production                      | 1.9                                   | 7.1%                    |
| Ethanol T&D                             | 4.1                                   | 15.4%                   |
| <b>Total Well-to-Tank</b>               | <b>26.6</b>                           | <b>100%</b>             |
| <b>Total Tank-to-wheel</b>              | <b>0</b>                              | <b>0%</b>               |
| <b>Total Well-to-Wheel</b>              | <b>26.6*</b>                          | <b>100%</b>             |

\*Note: The value of **26.6 gCO<sub>2</sub>e/MJ** does not include contributions from CH<sub>4</sub> and N<sub>2</sub>O when ethanol is blended with CARBOB and used as Reformulated Gasoline in a light-duty gasoline engine. The total GHG value including tailpipe contributions for sugarcane ethanol is **27.40 gCO<sub>2</sub>e/MJ** when blended with CARBOB (approximately 10% by volume ethanol). Details of this calculation are available in the CaRFG document available on the LCFS website ([www.arb.ca.gov/fuels/lcfs/lcfs.htm](http://www.arb.ca.gov/fuels/lcfs/lcfs.htm)).

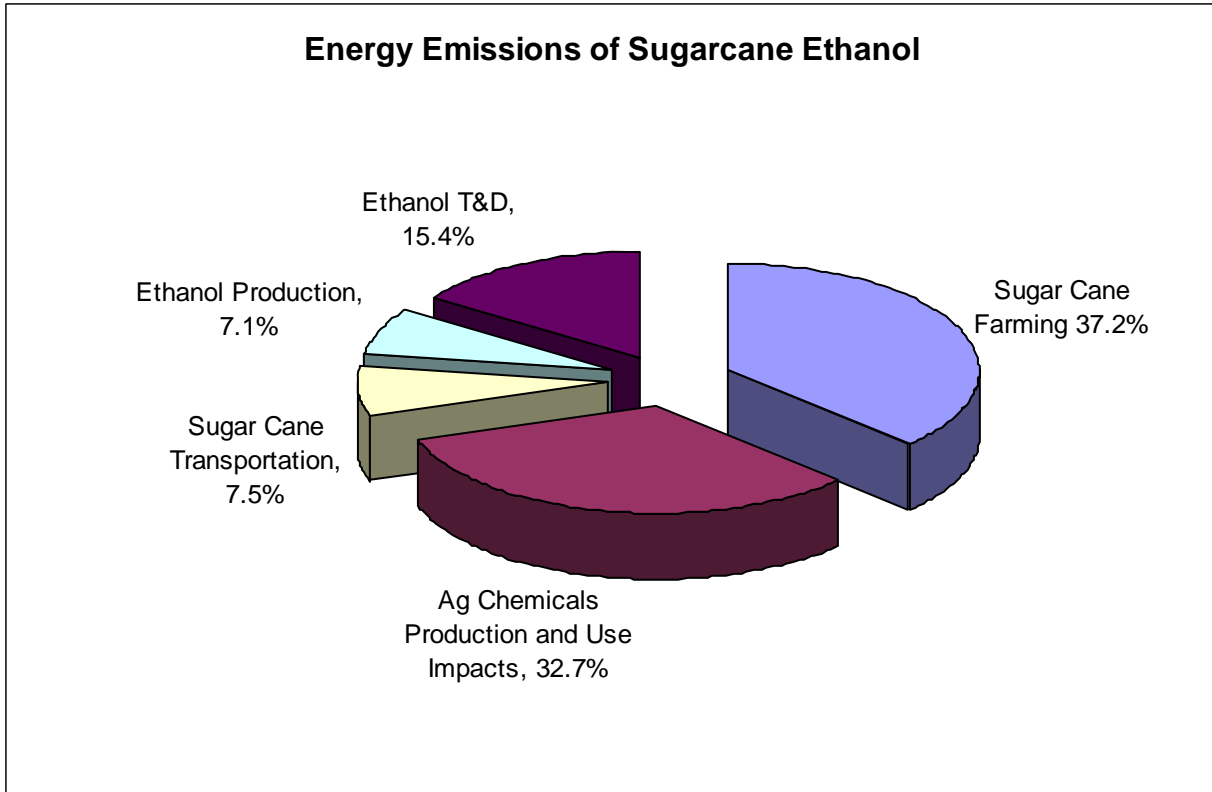


Figure 3. Percent GHG Emissions from WTW Sugarcane Ethanol

This section provides additional details of the energy and related GHG emissions for all the various baseline pathway components for sugarcane ethanol. Complete details including calculations, equations, etc. are provided in Appendices A1 and A2.

## Additional Details of the Sugarcane Ethanol Pathways

The first part of this section provides results for the energy use and GHG emissions for the baseline sugarcane ethanol pathway. These values are identical for the two additional scenarios modeled here. Later in this section, details pertaining to the impacts of the two additional scenarios on the baseline pathway GHG emissions are provided.

### SUGARCANE FARMING

Table D provides a breakdown of energy input from each fuel type used in sugarcane farming activities. Table E provides information on GHG emissions related to sugarcane farming. Additional details are provided in Appendix A1.

*Table D. Total Energy Input by Fuel Use for Sugarcane Farming*

| <b>Fuel Type</b>                                      | <b>Total Energy Use</b> |
|---|-------------------------|
| Diesel fuel (Btu/mmBtu)                               | 10,247                  |
| Gasoline (Btu/mmBtu)                                  | 3,401                   |
| Natural gas (Btu/mmBtu)                               | 5,213                   |
| Liquefied petroleum gas (Btu/mmBtu)                   | 4,790                   |
| Electricity (Btu/mmBtu)                               | 2,756                   |
| <b>Total Energy for Sugarcane Farming (Btu/mmBtu)</b> | <b>26,407</b>           |

*Table E. GHG Emissions from Sugarcane Farming and Straw Burning*

| <b>Emission Species</b>                                 | <b>Farming</b> | <b>Straw Burning</b> |
|---|----------------|----------------------|
| CH <sub>4</sub> (gCO <sub>2</sub> e/MJ)                 | < 0.01         | 6.6                  |
| N <sub>2</sub> O (gCO <sub>2</sub> e/MJ)                | 0.01           | 2.1                  |
| VOC (gCO <sub>2</sub> e/MJ)                             | < 0.01         | 2.2                  |
| CO (gCO <sub>2</sub> e/MJ)                              | < 0.01         | 14.4                 |
| CO <sub>2</sub> (gCO <sub>2</sub> e/MJ)                 | 1.69           | 163.20               |
| Biogenic CO <sub>2</sub> credit (gCO <sub>2</sub> e/MJ) | n/a            | (-180.31)            |
| <b>GHG Emissions (gCO<sub>2</sub>e/MJ)</b>              | <b>1.74</b>    | <b>8.2</b>           |
| <b>Total GHG Emissions (gCO<sub>2</sub>e/MJ)</b>        |                | <b>9.9</b>           |

INPUTS FOR AGRICULTURAL CHEMICALS

Table F provides details the energy inputs required to produce chemicals used in agricultural operations related to sugarcane farming. This includes fertilizers such as nitrogen, phosphorus, potassium (potash), and calcium carbonate (lime) as well as herbicides and insecticides. Table G provides details of the associated GHG emissions related to the production of these chemicals as well as their use in sugarcane farming. N<sub>2</sub>O and CO<sub>2</sub> emissions from the soil are based on the amount of fertilizer and lime applied respectively. Complete details are provided in Appendix A1.

*Table F. Energy Inputs for Agricultural Chemicals for Sugarcane Farming*

| <b>Chemical Type</b>                | <b>Energy Use</b> |
|-------------------------------------|-------------------|
| Nitrogen Fertilizer (Btu/mmBtu)     | 31,054            |
| Phosphate Fertilizer(Btu/mmBtu)     | 880               |
| Potash (Btu/mmBtu)                  | 885               |
| Lime (Btu/mmBtu)                    | 22,354            |
| Herbicide (Btu/mmBtu)               | 3,853             |
| Insecticide (Btu/mmBtu)             | 375               |
| <b>Total Energy Use (Btu/mmBtu)</b> | <b>59,616</b>     |

*Table G. Total GHG Emissions from Agricultural Chemical Use in Sugarcane Farming*

| <b>Ethanol Pathway</b>            | <b>Agricultural Chemicals</b> |                  |                  | <b>Soil N<sub>2</sub>O and NO</b> | <b>CO<sub>2</sub> from Application of Lime</b> | <b>Total</b> |
|-----------------------------------|-------------------------------|------------------|------------------|-----------------------------------|--|--------------|
|                                   | <b>Fertilizers</b>            | <b>Herbicide</b> | <b>Pesticide</b> |                                   |  |              |
| <b>GHGs (gCO<sub>2</sub>e/MJ)</b> | 3.7                           | 0.3              | 0.03             | 3.5                               | 1.2  | <b>8.7</b>   |

SUGARCANE TRANSPORT

Table H details the energy inputs required to transport sugarcane from the farm to the ethanol production plant using heavy duty trucks. Table I provides details of the associated GHG emissions related to transportation of sugarcane from the farm to the ethanol plant. Complete details are provided in Appendix A1.

*Table H. Sugarcane Transport Energy*

| <b>Transport Mode</b>                                   | <b>Energy Consumption</b> |
|---|---------------------------|
| <b>Total Energy for Sugarcane Transport (Btu/mmBtu)</b> | <b>25,722</b>             |

*Table I. Sugarcane Transport – Total GHG Emissions*

| <b>GHG Species</b>                               | <b>GHG Emissions</b> |
|--|----------------------|
| VOC (gCO <sub>2</sub> e/MJ)                      | < 0.01               |
| CH <sub>4</sub> (gCO <sub>2</sub> e/MJ)          | < 0.01               |
| N <sub>2</sub> O (gCO <sub>2</sub> e/MJ)         | < 0.01               |
| CO (gCO <sub>2</sub> e/MJ)                       | < 0.01               |
| CO <sub>2</sub> (gCO <sub>2</sub> e/MJ)          | 2.0                  |
| <b>Total GHG Emissions (gCO<sub>2</sub>e/MJ)</b> | <b>2.0</b>           |

ETHANOL PRODUCTION

Table J details the energy inputs required to produce ethanol from sugarcane for the baseline pathway. Table K provides details of the associated GHG emissions related to production of ethanol. Complete details are provided in Appendix A1.

*Table J. Ethanol Production Energy Use*

| <b>Fuel Type</b>   | <b>Total Energy</b> |
|--|---------------------|
| From Residual Oil (Btu/gal)                                  | 284                 |
| From Bagasse (Btu/gal)                                       | 83,132              |
| Total Energy Input for Ethanol Production (Btu/gal)          | 83,415              |
| <b>Total Energy Input for Ethanol Production (Btu/mmBtu)</b> | <b>1,093,743</b>    |

Table K. GHG Emissions for Ethanol Production

| <b>GHG Species</b>   | <b>GHG Emissions</b> |
|--|----------------------|
| CO <sub>2</sub> from Residual Oil (gCO <sub>2</sub> e/MJ)    | 0.03                 |
| CO <sub>2</sub> from Bagasse Burning (gCO <sub>2</sub> e/MJ) | 124.9                |
| CO <sub>2</sub> credit for Bagasse (gCO <sub>2</sub> e/MJ)   | -122.97              |
| CH <sub>4</sub> (gCO <sub>2</sub> e/MJ)                      | < 0.01               |
| N <sub>2</sub> O (gCO <sub>2</sub> e/MJ)                     | < 0.01               |
| VOC from Residual Oil (gCO <sub>2</sub> e/MJ)                | < 0.01               |
| VOC from Bagasse Burning (gCO <sub>2</sub> e/MJ)             | 0.02                 |
| VOC from non-combustion source (gCO <sub>2</sub> e/MJ)       | 0.09                 |
| CO from Residual Oil (gCO <sub>2</sub> e/MJ)                 | < 0.01               |
| CO from Bagasse Burning (gCO <sub>2</sub> e/MJ)              | 0.12                 |
| <b>Total GHG Emissions (gCO<sub>2</sub>e/MJ)</b>             | <b>1.9</b>           |

#### ETHANOL TRANSPORT AND DISTRIBUTION

Ethanol is transported within Brazil by rail or pipeline. It is then shipped to the US by ocean tanker. Several different denaturant blending options can apply to Brazilian ethanol. A significant fraction of ethanol imported to the U.S. is processed as hydrated ethanol (5% water) in the Caribbean where denaturant is also added. This delivery mode is not modeled in CA-GREET so the pathway based on delivering anhydrous ethanol to California is shown here. Once in California, it is blended with CARBOB and transported and distributed by heavy duty trucks. Table L details the energy inputs required to transport ethanol. Table M provides details of the associated GHG emissions related to ethanol transport and distribution. Additional details are provided in Appendix A1.

Table L. Energy Use for Ethanol Transport and Distribution

| <b>Transport Mode</b>                               | <b>Energy Use</b> |
|---|-------------------|
| <b>Transportation within Brazil and to US Port</b>  |                   |
| By Ocean Tanker (Btu/mmBtu)                         | 21,510            |
| By Rail (Btu/mmBtu)                                 | 4,614             |
| By Pipeline (Btu/mmBtu)                             | 3,056             |
| <b>Transportation within U.S</b>                    |                   |
| By Heavy Duty Truck (Btu/mmBtu)                     | 10,251            |
| <b>Distribution within US</b>                       |                   |
| By Heavy Duty Truck (Btu/mmBtu)                     | 2,460             |
| <b>Total Ethanol T&amp;D Energy Use (Btu/mmBtu)</b> | <b>44,442</b>     |



*Table M. GHG Emissions Related to Ethanol Transport and Distribution*

| <b>Transport Mode</b>                              | <b>GHG Emissions</b> |
|--|----------------------|
| <b>Transportation within Brazil and to US Port</b> |                      |
| By Ocean Tanker                                    | 1.81                 |
| By Rail (gCO <sub>2</sub> e/MJ)                    | 0.72                 |
| By Pipeline (gCO <sub>2</sub> e/MJ)                | 0.45                 |
| <b>Transportation within U.S</b>                   |                      |
| By Heavy Duty Truck (gCO <sub>2</sub> e/MJ)        | 0.81                 |
| <b>Distribution within US</b>                      |                      |
| By Heavy Duty Truck (gCO <sub>2</sub> e/MJ)        | 0.32                 |
| <b>Total GHG Emissions (gCO<sub>2</sub>e/MJ)</b>   | <b>4.1</b>           |

Since the CO<sub>2</sub> released from ethanol combustion is the carbon fixed during crop growth, the CO<sub>2</sub> emissions are not counted in the Life Cycle Analysis of sugarcane ethanol. Also, since ethanol is not used as a fuel but as an oxygenate in CaRFG, tailpipe emissions from use of anhydrous ethanol is not discussed in this document. Staff has provided a CaRFG (California Reformulated Gasoline) document which details the blending of ethanol into CARBOB for use as CaRFG and emissions from use of CaRFG ([www.arb.ca.gov/fuels/lcfs/lcfs.htm](http://www.arb.ca.gov/fuels/lcfs/lcfs.htm)).

**Details for Additional Scenarios 1 and 2 Modeled here**

FOR SCENARIO 1, WITH MECHANIZED HARVESTING AND EXPORT OF CO-PRODUCT ELECTRICITY

Table N provides a summary of the WTW GHG emissions for scenario 1. Complete details are provided in Appendix A2.

*Table N. WTW GHG Emissions for Scenario 1*

| <b>Description</b>  | <b>GHG Emissions</b> |
|---|----------------------|
| Baseline Pathway Emissions (gCO <sub>2</sub> e/MJ)              | 27.40                |
| Credit from Mechanized Harvest (gCO <sub>2</sub> e/MJ)          | -8.2                 |
| Electricity Co-product Credit (gCO <sub>2</sub> e/MJ)           | -7.0                 |
| <b>Total GHG Emissions for Scenario 1 (gCO<sub>2</sub>e/MJ)</b> | <b>12.20</b>         |

FOR SCENARIO 2 WITH EXPORT OF CO-PRODUCT ELECTRICITY

Table O provides a summary of the WTW GHG emissions for scenario 2. Complete details are provided in Appendix A2.

*Table O. WTW GHG Emissions for Scenario 2*

| <b>Description</b>  | <b>GHG Emissions<br/>(gCO<sub>2</sub>e/MJ)</b> |
|---|--|
| Baseline Pathway Emissions  | 27.40  |
| Electricity Co-product Credit                                       | -7.0   |
| <b>Total GHG Emissions for Scenario 2<br/>(gCO<sub>2</sub>e/MJ)</b> | <b>20.40</b>                                   |

## **APPENDIX A1 (BASELINE PATHWAY)**

### **AVERAGE BRAZILIAN SUGARCANE ETHANOL**

## SECTION 1. SUGARCANE FARMING

### 1.1 Energy Use for Sugarcane Farming

This section presents the direct energy inputs for sugarcane farming. For farming, the CA-GREET model calculates energy and emissions based on the quantity of fuel (Btu) and chemicals used per tonne of sugarcane, rather than using energy efficiencies, as the petroleum pathways do in CA-GREET. The total input energy per metric tonne of sugarcane is **41,592 Btu** (CA-GREET default) using a mix of fuel types shown in Table 1.01.

The Brazilian sugarcane ethanol pathway uses three different electricity mixes: Brazilian average, Brazilian marginal and U.S. average mix. The electricity mix used for sugarcane farming is the Brazilian average mix<sup>3</sup>, and U.S. electricity is the assumed input for fertilizer production (see Sections 2.1 and 2.2 in this Appendix). Marginal Brazilian electricity (natural gas) is the assumed electricity mix displaced by bagasse-fired exported electricity produced at the ethanol plant. Table 1.02 below shows generation shares of the three electricity mixes used in this fuel pathway.

*Table 1.01 Primary Energy Inputs by Fuel/Energy Input Type for Farm Operations*

| Fuel Type   | Fuel Share | Equation     | Primary Energy Input (Btu/tonne) | Primary Energy Input (Btu/mmBtu) |
|---|------------|--------------|----------------------------------|----------------------------------|
| Diesel Fuel   | 38.3%      | 41,592*38.3% | 15,930                           | 9,858                            |
| Gasoline  | 12.3%      | 41,592*12.3% | 5,116                            | 3,166                            |
| Natural Gas   | 21.5%      | 41,592*21.5% | 8,942                            | 5,534                            |
| Liquefied Petroleum Gas   | 18.8%      | 41,592*18.8% | 7,819                            | 4,839                            |
| Electricity   | 9%         | 41,592*9%    | 3,743                            | 2,316                            |
| <b>Direct Energy Consumption for Sugarcane Cultivation (unadjusted)</b> |            |              | <b>41,592</b>                    | <b>22,704</b>                    |

Note: To convert Btu/tonne (metric tonne) into the standard units of Btu/mmBtu, we use the following convention for anhydrous ethanol:

$$41,592 \text{ (Btu/tonne)} / (24 \text{ (gallons/tonne)} * 76,330 \text{ Btu/gal}) * 10^6 = 22,704 \text{ Btu/mmBtu}$$

where :

41,592 is a calculated value in Table 1.01

24 (gallons/tonne) = sugarcane EtOH yield (CA-GREET default)

76,330 Btu/gal = Low Heating Value of anhydrous ethanol (CA-GREET default)

<sup>3</sup> Brazilian Average Electricity Mix: <http://www.eia.doe.gov/emeu/cabs/Brazil/Full.html>

Table 1.02 General Shares of Electricity Mix in Brazil

| Fuel      | Brazilian Average Mix | U.S. Average Mix       | Brazilian Marginal Mix |
|-----------|-----------------------|------------------------|------------------------|
| Petroleum | 1.2%                  | 2.7%                   | 0.0%                   |
| NG        | 5.0%                  | 18.9%                  | 100.0%                 |
| Coal      | 1.7%                  | 50.7%                  | 0.0%                   |
| Biomass   | 4.2%                  | 1.3%                   | 0.0%                   |
| Nuclear   | 3.0%                  | 18.7%                  | 0.0%                   |
| Hydro     | 82.9%                 | (Included in "Others") | 0.0%                   |
| Others    | 2.0%                  | 7.7%                   | 0.0%                   |

The primary energy inputs do not include the upstream energy associated with the fuels. For example, the amount of energy associated with diesel does not include the energy and emissions associated with the making of the diesel fuel. CA-GREET accounts for the 'upstream' energy associated with fuels by multiplying with appropriate factors. Calculations are shown in Table 1.03. The factors A, B, etc. used in table 1.03 are defined in Table 1.04. Table 1.05 provides additional details for values used in Table 1.04.

Table 1.03 Calculating Total Energy Input by Fuel for Sugarcane Farming

| Fuel Type                                     | Equation  | Total Energy (Btu/tonne) | Total Energy (Btu/mmBtu) |
|---|---|--------------------------|--------------------------|
| Diesel fuel                                   | $A*[1+((B*C)+D/10^6)]$                                | 18,803                   | 10,247                   |
| Gasoline                                      | $E*[1+((B*F)+G/10^6)]$                                | 6,240.4                  | 3,400.8                  |
| Natural gas                                   | $H*(1+I)/10^6$  | 9,565.2                  | 5,212.7                  |
| LPG   | $(J)*(K)*(1+(I*L+M)/10^6) + (J)*(N)*(1+(P*O+Q)/10^6)$ | 8,789.3                  | 4,789.9                  |
| Electricity                                   | $R*S/10^6$  | 5,057.8                  | 2,756.3                  |
| <b>Total Energy for Sugarcane Cultivation</b> |   | <b>48,456</b>            | <b>26,407</b>            |

Note: Brazilian average electricity mix used. No energy inputs are included for agricultural machinery.

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Table 1.04 Values Used in Table 1.03

| <b>Factor</b> | <b>Description</b>                          | <b>Value</b>        | <b>Reference</b>         |
|---------------|---|---------------------|--------------------------|
| A             | Direct Diesel Input                         | 15,930 Btu/tonne    | calculated in Table 1.01 |
| B             | Crude Energy                                | 31,657 Btu/mmBtu    | CA-GREET calculated      |
| C             | Diesel Loss Factor                          | 1.00004             | CA-GREET default value   |
| D             | Diesel Energy                               | 125,303 Btu/mmBtu   | CA-GREET calculated      |
| E             | Direct Gasoline Input                       | 5,116 Btu/tonne     | calculated in Table 1.01 |
| F             | Gasoline Loss Factor                        | 1.00081             | CA-GREET default         |
| G             | Gasoline Energy                             | 169,676 Btu/mmBtu   | CA-GREET calculated      |
| H             | Direct NG Input                             | 8,942 Btu/tonne     | calculated in Table 1.01 |
| I             | NG Stationary Energy                        | 72,626 Btu/mmBtu    | CA-GREET calculated      |
| J             | Direct LPG Input                            | 7,819 Btu/tonne     | calculated in Table 1.01 |
| K             | NG for LPG Production Share                 | 60%                 | CA-GREET default         |
| L             | NG to LPG Loss Factor                       | 1.00006             | CA-GREET default         |
| M             | NG to LPG Fuel Stage Energy                 | 48,835 Btu/mmBtu    | CA-GREET calculated      |
| N             | Petroleum for LPG Production Share          | 40%                 | CA-GREET default         |
| O             | Petroleum to LPG Loss Factor                | 1.00012             | CA-GREET calculated      |
| P             | Petroleum to LPG Fuel Crude Energy          | 31,657 Btu/mmBtu    | CA-GREET calculated      |
| Q             | Petroleum to LPG Fuel Energy                | 75,622 Btu/mmBtu    | CA-GREET calculated      |
| R             | Direct Electricity Input                    | 3,743 Btu/tonne     | calculated in Table 1.01 |
| S             | Stationary Electricity Feedstock Production | 1,347,391 Btu/mmBtu | CA-GREET calculated      |

The factors listed in Table 1.04 are derived from the energy contributions of all other fuels that were used in processing these fuels. Those fuels are shown in Table 1.05 below, in two components: WTT energy (E) and Specific Energy (S) for each fuel type.

Table 1.05 Energy Consumption in the WTT Process and Specific Energy

| Factor/Operation /Fuel | WTT energy (Btu input/mmBtu product)   | S: Specific Energy (Btu input/Btu product)   |
|------------------------|--|--|
| Crude Recovery         | $WTT_{Crude Recovery} = 44,499$<br>(CA-GREET calculated)   | $S_{Crude Recovery} = 1 + WTT_{Crude Recovery} / 10^6 = 1.028$   |
| B                      | $WTT_{Crude} = WTT_{Crude Recovery} * LF_{T\&D} + WTT_{Crude T\&D} + WTT_{Crude Storage} = 28,249 * 1.00006 + 3,406 = 31,657$    | $LF_{T\&D} = \text{Loss Factor for Transport and Distribution} = 1.00006$ (CA-GREET default)<br>$WTT_{Crude T\&D} = 3,406$ (CA-GREET calculated)<br>$WTT_{Crude Storage} = 0.0$ (CA-GREET default)   |
| Residual Oil           | $WTT_{Res Oil} = 55,561$<br>(CA-GREET calculated)  | $S_{Res Oil} = 1 + (WTT_{Crude} * LF_{Crude} + WTT_{Res Oil}) / 10^6 = 1.106$<br>$LF_{Crude} = 1.00000$ (CA-GREET default)   |
| D                      | $WTT_{diesel} = 124,812$<br>(CA-GREET calculated)  | $S_{diesel} = 1 + (WTT_{Crude} * LF_{diesel} + WTT_{diesel}) / 10^6 = 1.157$ . $LF_{diesel} = 1.00004$ (CA-GREET default).   |
| G                      | $WTT_{gasoline} = 164,227$<br>(CA-GREET calculated)  | $S_{gasoline} = 1 + (WTT_{Crude} * \text{Loss Factor}_{gasoline} + WTT_{gasoline}) / 10^6 = 1.201$<br>$LF_{gasoline} = 1.00081$ (CA-GREET default)   |
| I                      | $WTT_{NG} = (WTT_{NG Recovery} * LF_{processing} + WTT_{NG Process}) * LF_{T\&D} + WTT_{T\&D} = 69,664$<br>(CA-GREET calculated) | $S_{NG} = 1 + WTT_{NG} / 10^6 = 1.073$<br>Natural Gas recovery, Process and T&D includes<br>$WTT_{NG Recovery} = 31,125$ , $WTT_{NG Process} = 31,843$ ,<br>$LF_{Processing} = 1.00148$ and $WTT_{NG T\&D} = 9,381$ .<br>$LF_{T\&D} = 1.00367$ (all CA-GREET calculated) |
| S                      | $WTT_{electricity} = 1,347,391$  | $S_{Electricity} = (WTT_{feedstock} + WTT_{fuel}) / 10^6 = 2.347$  |

Note:  $WTT_{Crude Recovery}$ : WTT energy for crude oil recovery, of self use of crude oil at the well, and does not include T&D.  $WTT_{Crude Storage}$ : WTT energy of crude storage

## 1.2 GHG Emissions from Sugarcane Farming

CA-GREET calculates carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O) emissions for each component of the pathway and uses IPCC<sup>4</sup> **G**lobal **W**arming **P**otentials (GWP) to calculate CO<sub>2</sub> equivalent values for CH<sub>4</sub> and N<sub>2</sub>O (see Table 1.06). For VOC and CO, CA-GREET uses a carbon ratio to calculate CO<sub>2</sub> equivalent values which are detailed in a note below Table 1.06. These are based on the oxidation of CO and VOC to CO<sub>2</sub> in the atmosphere.

Table 1.06 Global Warming Potentials for Gases

| GHG Species      | GWP (relative to CO <sub>2</sub> ) |
|------------------|------------------------------------|
| CO <sub>2</sub>  | 1                                  |
| CH <sub>4</sub>  | 25                                 |
| N <sub>2</sub> O | 298                                |

Carbon ratio of VOC = 0.85 grams CO<sub>2</sub>/MJ so grams VOC\*(0.85)\*(44/12) = 3.1

Carbon ratio of CO = 0.43 grams CO<sub>2</sub>/MJ so grams CO/mmBtu\*(0.43)\*(44/12) = 1.6

<sup>4</sup> Intergovernmental Panel on Climate Change a scientific intergovernmental body tasked to evaluate the risk of climate change caused by human activity established by United Nations in 1988.

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The GHG emissions for farm energy use are determined separately for CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O in CA-GREET using the direct energy inputs presented in Section 1.1 (Btu/tonne) and the combustion and upstream emissions for the energy inputs. CA-GREET calculates the emissions for each fossil fuel input by multiplying fuel input (Btu/tonne) by the total emissions from combustion, crude production and fuel production. The electricity emissions are calculated by multiplying the electricity input (Btu/tonne) by the total (feedstock plus fuel) emissions associated with the chosen electricity mix (from the “Electricity” tab in CA-GREET). Note that U. S. average emission factors are used for Brazilian fuel use and electricity generation. Table 1.07 below shows equations and calculated values by fuel type for sugarcane farming CO<sub>2</sub> emissions. Equations and values for CH<sub>4</sub> and N<sub>2</sub>O are not shown, but use the same structure. Table 1.08 provides values for parameters used in equations shown in Table 1.07.

Table 1.07 CA-GREET Calculations for CO<sub>2</sub> Emissions from Sugarcane Farming

| Fuel                                  | Equations  | CO <sub>2</sub> Emissions (g/tonne) | CO <sub>2</sub> Emissions (g/mmBtu) |
|---------------------------------------|--|-------------------------------------|-------------------------------------|
| Diesel                                | $[(A)*(B)*(C) + (D)*(E)+(F)*(G)+(H)*(I)+(J)*(K)+(L)]/10^6$ | 1,435                               | 782                                 |
| Gasoline                              | $[(M)*[(N)+ (J)*(O)+(P)]]/10^6$                            | 466                                 | 254                                 |
| Natural Gas                           | $[(Q)*[(R)*(S) + (T)*(U)+(V)*(W)+(X)*(Y)+(Z)]]/10^6$       | 552                                 | 301                                 |
| LPG                                   | $[(AA)*[(BB)+((J)*(CC)+(DD)+(EE)*(FF)+(GG))/2]]/10^6$      | 599                                 | 326                                 |
| Electricity                           | $[(HH)*(II)]/10^6$   | 69                                  | 38                                  |
| <b>Total CO<sub>2</sub> Emissions</b> |  | <b>3,120</b>                        | <b>1,701</b>                        |

To convert from g/tonne to g/mmBtu use:

$$3,120 \text{ (g/tonne)} / (24 \text{ (gallons/tonne)} * 76,330 \text{ Btu/gal}) * 10^6 = 1,701 \text{ g/mmBtu}$$

where:

24 (gallons/tonne) = sugarcane EtOH yield (CA-GREET default)

76,330 Btu/gal = Low Heating Value of anhydrous ethanol (CA-GREET default)

10<sup>6</sup> is to convert to mmBtu.



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Table 1.08 Input Values for Calculations in Table 1.06

|    | Relevant Parameters*   | Reference            |
|----|--|----------------------|
| A  | = Diesel input = 15,930 Btu/tonne                                    | Table 1.01           |
| B  | = % Fuel share diesel boiler = 0%                                    | CA-GREET default     |
| C  | = Boiler CO <sub>2</sub> emissions = 78,167 g/mmBtu                  | CA-GREET default     |
| D  | = % Fuel share diesel stationary engine = 0%                         | CA-GREET default     |
| E  | = IC Engine CO <sub>2</sub> Emissions = 77,401 g/mmBtu               | CA-GREET default     |
| F  | = % Fuel share diesel turbine = 0%                                   | CA-GREET default     |
| G  | = Turbine CO <sub>2</sub> emissions 78,179 g/mmBtu                   | CA-GREET default     |
| H  | = % Fuel share diesel tractor = 100%                                 | CA-GREET default     |
| I  | = Tractor CO <sub>2</sub> emissions = 77,411 g/mmBtu                 | CA-GREET default     |
| J  | = Crude production CO <sub>2</sub> emissions = 3,260 g/mmBtu         | CA-GREET calculation |
| K  | = Diesel loss factor = 1.00004                                       | CA-GREET default     |
| L  | = Diesel production CO <sub>2</sub> emissions = 9,387 g/mmBtu        | CA-GREET default     |
| M  | = Gasoline input = 5,116 Btu/tonne                                   | Table 1.01           |
| N  | = Farming tractor CO <sub>2</sub> emission factor = 75,645 g/mmBtu   | CA-GREET default     |
| O  | = Gasoline loss factor = 1.00081                                     | CA-GREET default     |
| P  | = Gasoline production CO <sub>2</sub> emissions = 12,122 g/mmBtu     | CA-GREET calculation |
| Q  | = NG input = 8,942 Btu/tonne   | Table 1.01           |
| R  | = % Fuel share NG engine = 100%                                      | CA-GREET default     |
| S  | = Engine CO <sub>2</sub> emission factor = 56,551 g/mmBtu            | CA-GREET default     |
| T  | = % Fuel share NG large turbine = 0%                                 | CA-GREET default     |
| U  | = Turbine CO <sub>2</sub> emission factor = 58,179 g/mmBtu           | CA-GREET default     |
| V  | = % Fuel share NG large boiler = 0%                                  | CA-GREET default     |
| W  | = Large boiler CO <sub>2</sub> emission factor = 58,198 g/mmBtu      | CA-GREET default     |
| X  | = % Fuel share small NG boiler = 0%                                  | CA-GREET default     |
| Y  | = Small boiler CO <sub>2</sub> emission factor = 58,176 g/mmBtu      | CA-GREET default     |
| Z  | = WTT stationary NG CO <sub>2</sub> emissions = 5,218 g/mmBtu        | CA-GREET calculation |
| AA | = LPG input = 7,819 Btu/tonne  | Table 1.01           |
| BB | = Commercial boiler CO <sub>2</sub> emission factor = 68,036 g/mmBtu | CA-GREET default     |
| CC | = LPG loss factor = 1.00012  | CA-GREET default     |
| DD | = LPG production CO <sub>2</sub> emissions = 5,708 g/mmBtu           | CA-GREET calculation |
| EE | = LNG feedstock CO <sub>2</sub> emissions = 4,882 g/mmBtu            | CA-GREET calculation |
| FF | = NG to LPG loss factor = 1.00006                                    | CA-GREET default     |
| GG | = NG to LPG fuel CO <sub>2</sub> emissions = 3,162 g/mmBtu           | CA-GREET calculation |
| HH | = Electricity input = 3,743 Btu/tonne                                | Table 1.01           |
| II | = Electricity CO <sub>2</sub> emissions = 18,504 g/mmBtu             | CA-GREET calculation |

Other GHGs, including VOC, CO, CH<sub>4</sub>, and N<sub>2</sub>O emissions are calculated with the same equations, energy input, and loss factors as CO<sub>2</sub> emissions calculations shown in Tables 1.07 and 1.08, but with different VOC, CO, CH<sub>4</sub>, and N<sub>2</sub>O emission factors. Table 1.09 shows the results of the calculations of VOC, CO, CH<sub>4</sub>, and N<sub>2</sub>O in (g/tonne) then converted to g/mmBtu. The conversion is performed as shown in the note below Table 1.07.

Table 1.09 GHG Emissions from Sugarcane Farming

| Emission Species           | Emissions <sup>1</sup><br>(g/tonne) | GHGs<br>(gCO <sub>2</sub> e/mmBtu) | GHGs<br>(gCO <sub>2</sub> e/MJ) |
|----------------------------|-------------------------------------|------------------------------------|---------------------------------|
| CH <sub>4</sub>            | 7.82                                | 106.5                              | 0.1                             |
| N <sub>2</sub> O           | 0.08                                | 11.9                               | 0.01                            |
| CO <sub>2</sub>            | 3,035                               | 1,654                              | 1.57                            |
| <b>Total GHG Emissions</b> |                                     | <b>1,772</b>                       | <b>1.7</b>                      |

<sup>1</sup>Emissions in grams of gaseous species per tonne. To convert all VOC, CO, CH<sub>4</sub> and N<sub>2</sub>O (g/tonne) to (g/mmBtu) = (g/tonne)/(Ethanol Yield (gal/tonne) \* LHV of Anhydrous Ethanol (Btu/gal))\*10<sup>6</sup>. Note that non-CO<sub>2</sub> gases expressed as GHG in gCO<sub>2</sub>e/mmBtu were converted to CO<sub>2</sub>e

### 1.3 GHG Emissions from Straw Burning in Field

The sugarcane field is burned prior to manual harvesting. The fire removes dry leaves and straw and kills any pests present while leaving the wet, sugar-rich stalks undamaged. The CA-GREET model uses assumptions shown below in Table 1.10 and emission factors presented in Table 1.11 to calculate emissions from field burning. An emission credit is also calculated in grams of CO<sub>2</sub>/tonne cane, assuming that all carbon in burned residue is converted to CO<sub>2</sub>.

Table 1.10 Inputs for Calculating Field Burning Emissions

| Sugarcane Straw Burning Input Parameters | Straw Yield<br>(Dry tonne straw/tonne cane) | Straw C Ratio<br>(% by weight) |
|--|---|--------------------------------|
|  | 0.190                                       | 50.0%                          |

Table 1.11 Sugarcane Straw Burning Emission Factors

| Emission Species                       | CO <sub>2</sub> EF | VOC EF | CO EF | CH <sub>4</sub> EF | N <sub>2</sub> O EF |
|--|--------------------|--------|-------|--------------------|---------------------|
| Emission Factor<br>(g/kg straw burned) | 1,660              | 7.0    | 92.0  | 2.7                | 0.07                |

The straw burning emissions for CO<sub>2</sub> are calculated as follows:

$$(1,660 \text{ g/kg straw})(0.190 \text{ dry tonne straw/tonne cane})(1,000 \text{ kg/tonne}) = \mathbf{315,973 \text{ g/tonne cane}}$$

The CO<sub>2</sub> emission credit is calculated as follows:

$$-(0.190 \text{ dry tonne straw/tonne cane}) * (50.0\% \text{ C content by wt.}) * (1,000 \text{ kg/tonne}) * (1,000 \text{ g/Kg}) * (44/12) = \mathbf{-349,067 \text{ g/tonne cane}}$$

Table 1.12 shows all emission species calculated the same way as CO<sub>2</sub> example above.

Table 1.12 Sugarcane Straw Burning Emissions

| <b>Emission Species</b>                          | <b>Emissions<br/>(g/tonne cane)</b> | <b>GHG Emissions<br/>(gCO<sub>2</sub>e/mmBtu)</b> | <b>GHG Emissions<br/>(gCO<sub>2</sub>e/MJ)</b> |
|--|-------------------------------------|---|--|
| VOC  | 1,332.80                            | 2,287   | 2.2  |
| CO   | 17,516.80                           | 15,204  | 14.4   |
| CH <sub>4</sub>                                  | 514.1                               | 7,003.90  | 6.6  |
| N <sub>2</sub> O                                 | 13.3                                | 2,164.50  | 2.1  |
| CO <sub>2</sub>                                  | 315,973                             | 172,195   | 163.2  |
| Biogenic CO <sub>2</sub> Credit                  | -349,067                            | -190,230  | -180.3   |
| Total GHG Emissions                              |                                     | 23,226  |  |
| <b>Total GHG Emissions (gCO<sub>2</sub>e/MJ)</b> |                                     |   | <b>8.2</b>                                     |

The same notes under Table 1.09 apply for this table.

Total GHG emissions from sugarcane farming and straw burning is therefore **1.74 + 8.2 = 9.9 gCO<sub>2</sub>e/MJ**.

## SECTION 2. INPUTS FOR AGRICULTURAL CHEMICALS

### 2.1 Energy Calculations for Production of Chemical Inputs

Chemical inputs, including fertilizer, herbicide and insecticide, are input on a g-nutrient/tonne (fertilizer) or g-product/tonne (herbicide and pesticide) basis. Table 2.01 below presents the CA-GREET chemical inputs per metric tonne of sugarcane, the total energy required to produce the chemical product and the calculated upstream energy required to produce a bushel of sugarcane using these inputs. Both chemical input values and product energy values are CA-GREET defaults.

*Table 2.01 Sugarcane Farming Chemical Inputs*

| Chemical Type         | Chemical Input (Btu/g) | Product Input Factors (g/tonne) | Total Energy Use (Btu/tonne) | Total Energy Use (Btu/mmBtu) |
|-----------------------|------------------------|---------------------------------|------------------------------|------------------------------|
| Nitrogen Fertilizer   | 45.9                   | 1,091.7                         | 50,133                       | 31,054                       |
| Phosphate Fertilizer  | 13.3                   | 120.8                           | 1,604                        | 880                          |
| Potash                | 8.4                    | 193.6                           | 1,624                        | 892                          |
| Lime                  | 7.7                    | 5,337.7                         | 41,019                       | 22,512                       |
| Herbicide (average)   | 262.8                  | 26.9                            | 7,070                        | 3,898                        |
| Insecticide (average) | 311.3                  | 2.21                            | 688                          | 379                          |
| <b>Total</b>          |                        |                                 |                              | <b>59,616</b>                |

Note: Ethanol yields for sugarcane ethanol are assumed to be 24 gal/tonne in CA-GREET. The WTT energy = chemical input (g/tonne)\* product input energy (Btu/g).

Example Calculation:

For Nitrogen Fertilizer: WTT Energy (Btu/tonne) = 45.9 (Btu/g) \* 1,092 (g/tonne) = **50,133 Btu/tonne**

To convert Btu/tonne into the standard units of Btu/mmBtu, we use the following:

$(50,133 \text{ Btu/tonne}) / ((24 \text{ gallons/tonne}) * 76,330 \text{ Btu/gal}) * 10^6 = \mathbf{59,616 \text{ Btu/mmBtu}}$   
where :

50,133 is a calculated value in Table 2.01

24 gallons/tonne = sugarcane EtOH yield (CA-GREET default)

76,330 Btu/gal = Lower Heating Value of anhydrous ethanol (CA-GREET default)

CA-GREET models nitrogen fertilizer as a weighted average of ammonia (70.7%), urea (21.1%) and ammonium nitrate (8.2%) fertilizers. As Table 2.01 shows, nitrogen fertilizer input accounts for more than half of total chemical energy input. The herbicide production energy is a weighted average of four types of herbicides used: atrazine (31.2%), metolachlor (28.1%), acetochlor (23.6%) and cyanazine (17.1%). The

insecticide inputs represent an “average” insecticide, rather than an explicitly weighted average of specific insecticides. The energy required to produce nitrogen fertilizers, herbicides or pesticides does not vary significantly by category, attesting to the validity of using average energy inputs.

## 2.2 GHG Calculation from Production and Use of Agricultural Chemicals

This component includes all of the upstream emissions related to the manufacturing of agricultural chemical products. It also includes impacts from the use of agricultural chemicals in farming. Upstream emissions are calculated in CA-GREET per metric tonne of product, including the production, process and transportation emissions associated with manufacturing chemicals; these intermediate calculations take place in the “*Ag\_Inputs*” sheet. These values are converted to emissions per tonne of nutrient using the ratio of nutrient to product.

Nitrogen fertilizer greenhouse emissions are modeled as a weighted average of 3 types of N-fertilizers modeled in CA-GREET. Energy and emissions are converted to Btu or grams greenhouse gases per g of nutrient (fertilizer) or product (herbicide and pesticide). Average emissions for herbicides are calculated using a weighted average of 4 types of herbicides while pesticide emissions are based on a single pesticide type. Table 2.02 below shows the greenhouse emissions for agricultural chemicals in grams per gram of nutrient for fertilizers and per gram of product for herbicides and pesticides. The equations are complex and not shown here since agricultural inputs apply to large variety of crop cultivation and are not specific to sugarcane cultivation.

Table 2.02 Calculated GHG Emissions (g/g) Associated with Production of Agricultural Chemicals

| GHG Type                    | Nitrogen (weighted average) | P <sub>2</sub> O <sub>5</sub> | K <sub>2</sub> O | CaCO <sub>3</sub> | Herbicide (weighted average) | Pesticide    |
|-----------------------------|-----------------------------|-------------------------------|------------------|-------------------|------------------------------|--------------|
| CH <sub>4</sub>             | <0.01                       | <0.01                         | <0.01            | <0.01             | 0.03                         | 0.03         |
| N <sub>2</sub> O            | <0.01                       | <0.01                         | <0.01            | <0.01             | <0.01                        | <0.01        |
| CO <sub>2</sub>             | 2.39                        | 0.98                          | 0.66             | 0.60              | 20.53                        | 23.87        |
| <b>Convert to GHG (g/g)</b> | <b>2.9</b>                  | <b>1.0</b>                    | <b>0.7</b>       | <b>0.6</b>        | <b>21.3</b>                  | <b>24.84</b> |

The greenhouse emissions of agricultural inputs are multiplied by chemical input factors (g/tonne) in the “*Ethanol*” tab and a loss factor from the “*Ag\_Inputs*” tab to yield fertilizer emissions in grams per bushel of sugarcane produced. Table 2.03 below shows the calculations for CO<sub>2</sub> emissions associated with the use of chemical inputs in g/tonne of sugarcane produced. Table 2.04 details the values used in calculations in Table 2.03. The equations for CH<sub>4</sub> and N<sub>2</sub>O are analogous to these calculations and are not shown. Table 2.05 shows the emission results for all greenhouse gases for chemical use, based on the calculations shown in Table 2.03.

Table 2.03 Calculated CO<sub>2</sub> Emissions Associated with Production of Agricultural Chemicals

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| Chemical Product   | Equation    | CO <sub>2</sub> Emissions |              |                        |
|--|-------------|---------------------------|--------------|------------------------|
|  |             | (g/tonne)                 | (g/mmBtu)    | (gCO <sub>2</sub> /MJ) |
| Nitrogen (weighted average)                                | (A)*(B)*(C) | 2,971                     | 1,619        |                        |
| P <sub>2</sub> O <sub>5</sub>                              | (D)*(E)*(F) | 118                       | 64           |                        |
| K <sub>2</sub> O   | (G)*(H)*(I) | 127                       | 69           |                        |
| CaCO <sub>3</sub>  | (J)*(K)*(L) | 3,210                     | 1,749        |                        |
| Herbicide  | (M)*(N)*(O) | 552                       | 301          |                        |
| Pesticide  | (P)*(Q)*(R) | 53                        | 29           |                        |
| <b>Total CO<sub>2</sub> emissions (gCO<sub>2</sub>/MJ)</b> |             | <b>7,031</b>              | <b>3,832</b> | <b>3.63</b>            |

Table 2.04 Calculated GHG Emissions (g/g) Associated with Production of Agricultural Chemicals

| Variables | Relevant Parameters   | Reference        |
|-----------|---|------------------|
| A         | Nitrogen input = 1,091.7 g/tonne  | CA-GREET default |
| B         | Nitrogen chemical cycle emissions = 2.39 g/g  | Table 2.02       |
| C         | Nitrogen loss factor = 1.0 (during transport, distribution...)                      | CA-GREET default |
| D         | P <sub>2</sub> O <sub>5</sub> input = 120.8 g/tonne                                 | CA-GREET default |
| E         | P <sub>2</sub> O <sub>5</sub> chemical cycle emissions = 0.98 g/g                   | Table 2.02       |
| F         | P <sub>2</sub> O <sub>5</sub> loss factor = 1.0 (during transport, distribution...) | CA-GREET default |
| G         | K <sub>2</sub> O input = 193.6 g/tonne  | CA-GREET default |
| H         | K <sub>2</sub> O chemical cycle emissions = 0.66 g/g                                | Table 2.02       |
| I         | K <sub>2</sub> O loss factor = 1.0 (during transport, distribution...)              | CA-GREET default |
| J         | CaCO <sub>3</sub> input = 5,337.7 g/tonne   | CA-GREET default |
| K         | CaCO <sub>3</sub> chemical cycle emissions = 0.60 g/g                               | Table 2.02       |
| L         | CaCO <sub>3</sub> loss factor = 1.0 (during transport, distribution...)             | CA-GREET default |
| M         | Herbicide input = 26.9 g/tonne  | CA-GREET default |
| N         | Herbicide chemical cycle emissions = 20.53 g/g                                      | Table 2.02       |
| O         | Herbicide loss factor = 1.0   | CA-GREET default |
| P         | Pesticide input = 2.21 g/tonne  | CA-GREET default |
| Q         | Pesticide chemical cycle emissions = 23.87 g/g                                      | Table 2.02       |
| R         | Pesticide loss factor = 1.0   | CA-GREET default |

Table 2.05 shows the emission results (g/tonne) for all GHG emissions for production of chemicals used in agriculture based on the calculations shown in Table 2.03. The CH<sub>4</sub> and N<sub>2</sub>O emissions results shown in Table 2.05 are calculated with the same equations

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as CO<sub>2</sub> emission calculations, except that CO<sub>2</sub> emission factors are replaced by CH<sub>4</sub> and N<sub>2</sub>O emission factors. Table 2.05 also shows the WTT emissions on an energy basis. Note that converting from g/tonne to g/mmBtu is shown in a note below Table 2.05. To convert from g/mmBtu to gCO<sub>2</sub>e/mmBtu, non-CO<sub>2</sub> gasses are adjusted using their respective GWPs.

Table 2.05 Calculated GHG Emissions from Production of Agricultural Chemicals

| GHG Type   | Nitrogen (weighted average) | P <sub>2</sub> O <sub>5</sub> | K <sub>2</sub> O | CaCO <sub>3</sub> | Total Fert.  | Herbicide (weighted average) | Pesticide   | Total        |
|--|-----------------------------|-------------------------------|------------------|-------------------|--------------|------------------------------|-------------|--------------|
| CH <sub>4</sub> (g/tonne)                        | 3.1                         | 0.2                           | 0.2              | 4.9               |              | 0.8                          | 0.1         | 9.3          |
| N <sub>2</sub> O (g/tonne)                       | 1.8                         | <0.01                         | <0.01            | 0.05              |              | <0.01                        | <0.01       | 1.8          |
| CO <sub>2</sub> (g/tonne)                        | 2,971                       | 118                           | 127              | 3,210             |              | 552                          | 53          | 6,743.4      |
| GHGs (g/tonne)                                   | 3,579                       | 124                           | 133              | 3,344             |              | 574                          | 55          | 7524.2       |
| GHGs (g/mmBtu)                                   | <b>1,951</b>                | <b>68</b>                     | <b>72</b>        | <b>1,822</b>      | <b>3,913</b> | <b>313</b>                   | <b>30</b>   | <b>4,256</b> |
| <b>Total GHG Emissions (gCO<sub>2</sub>e/MJ)</b> | <b>1.85</b>                 | <b>0.06</b>                   | <b>0.07</b>      | <b>1.73</b>       | <b>3.70</b>  | <b>0.30</b>                  | <b>0.03</b> | <b>4.03</b>  |

Note: To convert (g/tonne) to (g/mmBtu) = (g/tonne)/(Ethanol Yield (gal/tonne) \* LHV of Anhydrous Ethanol (Btu/gal))\*10<sup>6</sup>. LHV of denatured ethanol is 76,330 Btu/gal and ethanol yield is assumed to be 24 gal/tonne.

**Impact of soil N<sub>2</sub>O emissions resulting from nitrogen fertilizer use on WTT GHG emissions**

CA-GREET also calculates direct field and downstream N<sub>2</sub>O emissions resulting from nitrogen fertilizer input. Table 2.06 below shows the two main inputs: fertilizer input (g/tonne) and percent conversion of N-input to N<sub>2</sub>O. The table shows the N<sub>2</sub>O emissions on an energy basis. CA-GREET v1.8b assumes 1.3% of fertilizer-N is ultimately converted to N<sub>2</sub>O. The calculation also uses the mass ratio of N<sub>2</sub>O to N<sub>2</sub> (44/28). Table 2.06 provides total GHG impacts from soil N<sub>2</sub>O emissions.

Table 2.06 Inputs and Calculated Emissions for Soil NO and N<sub>2</sub>O from Sugarcane Farming

|                  | Fertilizer N input (g/tonne) | Percent conversion to N <sub>2</sub> O-N | N <sub>2</sub> O formed/ N <sub>2</sub> O-N (g/g) | N Converted (g/tonne) | N <sub>2</sub> O or NO Emissions (g/tonne) | GHG Emissions (g/mmBtu) | GHG Emissions (gCO <sub>2</sub> e/MJ) |
|------------------|------------------------------|--|---|-----------------------|--|-------------------------|---------------------------------------|
| N <sub>2</sub> O | 1,091.7                      | 1.3%                                     | 44/28   | 14.5                  | 22.7                                       | 3,691                   | <b>3.5</b>                            |

Note: Soil N<sub>2</sub>O emissions = (1,091.8 g N/tonne)(1.3%)(44 g N<sub>2</sub>O/28 g N<sub>2</sub>) = 22.7 g N<sub>2</sub>O/tonne  
 N<sub>2</sub>O Emissions: N in N<sub>2</sub>O as % of N in N fertilizer and biomass: CA-GREET default of 1.3%

**Effect of Lime (CaCO<sub>3</sub>) added to soil on GHG emissions**

CA-GREET assumes that all of the carbon in added lime is emitted as CO<sub>2</sub>. This results in the following CO<sub>2</sub> emission: Soil CO<sub>2</sub> emissions = (5,337.7 g CaCO<sub>3</sub>/tonne)\*(44 g CO<sub>2</sub>/100 g CaCO<sub>3</sub>) = 2,349 g CO<sub>2</sub>/tonne = 1,282 g CO<sub>2</sub>/mmBtu = 1.2 g CO<sub>2</sub>/MJ.

Tables 2.05, 2.06 and emissions from adding lime to soil are combined to provide the total GHG emissions from the use of Agricultural Chemicals and is detailed in Table 2.07.

*Table 2.07 Total GHG Emissions from Agricultural Chemical Use for Sugarcane Ethanol*

| <b>Ethanol Pathway</b>            | <b>Fertilizers</b> | <b>Herbicide</b> | <b>Pesticide</b> | <b>Soil N<sub>2</sub>O and NO</b> | <b>CO<sub>2</sub> from CaCO<sub>3</sub></b> | <b>Total (gCO<sub>2</sub>e/MJ)</b> |
|-----------------------------------|--------------------|------------------|------------------|-----------------------------------|---|------------------------------------|
| <b>GHGs (gCO<sub>2</sub>e/MJ)</b> | 3.7                | 0.3              | 0.03             | 3.5                               | 1.2   | <b>8.7</b>                         |



## SECTION 3. SUGARCANE TRANSPORT

### 3.1 Energy for Sugarcane Transportation

CA-GREET calculates the total energy needed (Btu/tonne) to transport sugarcane from the field to the ethanol production facility using heavy duty trucks. Table 3.01 below shows the sugarcane transportation distance and energy inputs. The calculations are based on heavy duty truck capacities of 17 tonnes. The default transport distance modeled is 12 miles. CA-GREET calculates the diesel energy per tonne mile based on the cargo capacity of the truck and its fuel economy and assumes that truck trips carrying sugarcane and returning empty use the same energy. All values are CA-GREET default values.

Table 3.01 Sugarcane Transport Inputs

| Transport Mode         | Energy Intensity (Btu/tonne-mile) | Distance from Origin to Destination (mi) | Capacity (tonnes) | Fuel Consumption (mi/gal) | Energy Consumption of Truck (Btu/mi) | Share of Diesel Used |
|------------------------|-----------------------------------|--|-------------------|---------------------------|--------------------------------------|----------------------|
| Field to Ethanol Plant | 1,511                             | 12                                       | 17                | 5                         | 25,690                               | 100%                 |

The calculated sugarcane transport energy on a Btu per tonne of sugarcane basis is shown below in Table 3.02 using the values in Table 3.01.

Table 3.02 Sugarcane Transport Energy

| Transport Mode                       | Energy Consumption (Btu/ton)   |
|--------------------------------------|--|
| Field to Ethanol Plant               | (12 miles one-way distance)*(1,511 Btu/ton-mile origin to destination + 1,511 Btu/ton-mile back-haul)*(Diesel share 100%)*(1+Diesel WTT Energy 0.157 Btu/Btu) /0.907 (tonnes/ton) = 47,200 Btu/tonne |
| Total Energy Used (Btu/tonne)        | 47,200   |
| <b>Total Energy Used (Btu/mmBtu)</b> | <b>25,722</b>  |

Note: To convert (Btu/ton) to (Btu/mmBtu) = (Btu/ton)/(0.907 tonnes/ton)/(Ethanol Yield (gal/tonne) \* LHV of Anhydrous Ethanol (Btu/gal))\*10<sup>6</sup>. Diesel WTT energy is a CA-GREET calculation

### 3.2 GHG Calculations from Sugarcane Transportation

GHG emissions from sugarcane transportation are calculated from section 3.1 above with the same transportation mode, miles traveled, etc. as indicated by Table 3.01 above. Table 3.03 below details key assumptions of calculating GHG from sugarcane transportation. All values used in calculations are CA-GREET default values.

*Table 3.03 Key Assumptions in Calculating GHG Emissions from Sugarcane*

| Transport Mode                         | Energy Intensity (Btu/ton-mile) | Distance from Origin to Destination (mi) | CO <sub>2</sub> Emission Factors of Truck (g/mi) | WTT Transport Diesel Emissions (g/mmBtu) | CO <sub>2</sub> Emission Factors of Diesel Combustion (g/mmBtu) |
|--|---------------------------------|--|--|--|---|
| Sugarcane to plant by heavy duty truck | 1,511                           | 12                                       | 1,999<br>(2,002)*                                | 12,647                                   | 77,809<br>(77,913)*   |

Note: \*values in parenthesis are for the return trips.

Sugarcane transport emissions are first calculated on a g/ton basis and then finally converted to g/mmBtu as shown in Table 3.04 below.

*Table 3.04 Sugarcane Transport -CO<sub>2</sub> Emissions*

| Transport Mode   | CO <sub>2</sub> Emission (g/tonne) | CO <sub>2</sub> Emissions (g/mmBtu) |
|--|------------------------------------|-------------------------------------|
| Sugarcane to Ethanol Plant by Heavy Duty Truck             | 3,701                              | 2,017                               |
| <b>Total CO<sub>2</sub> Emissions (gCO<sub>2</sub>/MJ)</b> |                                    | <b>2.0</b>                          |

Note: Example formula to calculate CO<sub>2</sub> emission of Heavy Duty Truck above:

$$[(77,809 \text{ g/mmBtu}) + (12,647 \text{ g/mmBtu}) * (100\% \text{ diesel used})] * (1,511 \text{ Btu/ton-mile}) + [(77,913 \text{ g/mmBtu}) + (12,647 \text{ g/mmBtu}) * (100\% \text{ diesel used})] * 1,511 \text{ Btu/ton-mile} * 12 \text{ miles} / 0.907 \text{ ton/tonne} / (10^6 \text{ mmBtu/Btu}) = 3,701 \text{ g/tonne}.$$

To convert (g/tonne) to (g/mmBtu) = (g/tonne) / (Ethanol Yield (gal/tonne) \* LHV of Anhydrous Ethanol (Btu/gal)) \* 10<sup>6</sup>.

Similarly, CH<sub>4</sub>, N<sub>2</sub>O, VOC, and CO are calculated the same way (with different emission factors for each species) and shown in Table 3.05. All emissions are converted to a CO<sub>2</sub> equivalent-basis. The emissions are shown on an anhydrous ethanol basis.

*Table 3.05 Sugarcane Transport – Total GHG Emissions*

|                             | <b>CH<sub>4</sub></b> | <b>N<sub>2</sub>O</b> | <b>VOC</b>      | <b>CO</b>       | <b>CO<sub>2</sub></b> | <b>GHG Emissions (gCO<sub>2</sub>e/MJ)</b> |
|-----------------------------|-----------------------|-----------------------|-----------------|-----------------|-----------------------|--|
| (g/tonne)                   | 4.078                 | 0.088                 | 1.493           | 6.553           | 3,701                 |  |
| (g/mmBtu)                   | 2.222                 | 0.048                 | 0.814           | 3.571           | 2,017                 | 2,087                                      |
| <b>Total GHG Emisisions</b> | <b>&lt;0.01</b>       | <b>&lt;0.01</b>       | <b>&lt;0.01</b> | <b>&lt;0.01</b> | <b>2.0</b>            | <b>2.0</b>                                 |

## SECTION 4. ETHANOL PRODUCTION

### 4.1 Ethanol Production

Similar to the sugarcane farming energy calculations, CA-GREET uses energy input values for sugarcane ethanol in Btu/gallon of anhydrous ethanol and uses fuel shares to allocate this direct energy input to process fuels. Part of the bagasse, the fibrous residue remaining after squeezing the juice of the plant, is currently burned at the mill to provide heat for distillation and electricity to run machinery at the plant. This allows ethanol plants to be energetically self-sufficient and even sell surplus electricity to utilities in some cases.

A major portion of the energy used in sugarcane ethanol plant in Brazil is from bagasse (a fiber material of the sugarcane plant). Sucrose accounts for little more than 30% of the chemical energy stored in the mature plant; 35% is in the leaves and stem tips, which are left in the fields during harvest, and 35% are in the fibrous residue (bagasse).

Table 4.01 shows the ethanol production fuel shares and energy inputs per gallon of anhydrous ethanol. The electricity input is represented in Btu/gal and added to the process fuel consumption to determine the fuel shares. Additional details are shown in Table 4.02.

*Table 4.01 Sugarcane Ethanol Fuel Shares and Primary Energy Inputs*

| Fuel Type    | Fuel Share  | Primary Energy Input (Btu/gallon) |
|--------------|-------------|-----------------------------------|
| Bagasse      | 99.65%      | 83,132                            |
| Residual Oil | 0.35%       | 278                               |
| <b>Total</b> | <b>100%</b> | <b>83,409</b>                     |

Note:

For Bagasse: 0.00642 US ton of dry bagasse/gal ethanol \*12,947,318 (Btu/US ton) LHV = **83,132 Btu/gal**  
 For Residual oil: Oil use in sugarcane ethanol plants is from lubricant use. For CO<sub>2</sub> calculation, it is assumed that 10% of lubricants are burned.

Tables 4.02 and 4.03 show the CA-GREET equations, parameters and energy inputs for ethanol production. The tables show the total input energy per mmBtu of anhydrous ethanol. For this document, ethanol transported from Brazil is considered as anhydrous which is subsequently blended to make denatured ethanol in California.

Table 4.02 Sugarcane Ethanol Production Parameters and Total Energy Use

| Fuel Type  | Formula  | Relevant Parameters                                       | Total Energy     |
|--|--|---|------------------|
| Bagasse  | Dry tonne bagasse/gal ethanol *Bagasse LHV   | Dry tonne bagasse/gal ethanol = 0.00642 tonne/gal         | 83,132 (Btu/gal) |
|  |  | Bagasse LHV = 12,947,318 Btu/tonne (CA-GREET default)     |                  |
| Residual Oil   | (Direct Residual Oil Input)* (1+(WTT Crude Oil Energy*Loss Factor + WTT of residual oil)/10 <sup>6</sup> ) | Direct residual oil input = 251 Btu/gal                   | 284 (Btu/gal)    |
|  |  | WTT crude oil energy = 31,657 Btu/mmBtu                   |                  |
|  |  | Loss Factor = 1.001                                       |                  |
|  |  | WTT of residual oil = 74,001Btu/mmBtu                     |                  |
| Total energy input for ethanol production (Btu/gal)          |  |   | 83,415           |
| <b>Total energy input for ethanol production (Btu/mmBtu)</b> |  | 83,415 Btu/gal / (76,330 Btu/gal) *10 <sup>6</sup> *1.001 | <b>1,093,376</b> |

Note: 1.001 is the loss factor by CA-GREET default

#### 4.2 GHG Emissions from Ethanol Production

Sugarcane mill ethanol production in Brazil is assumed here to use dry bagasse as fuel for small boilers (99.65%). A relatively small amount of residual oil is also utilized in the process (about 0.35%). GHG from ethanol production by burning bagasse is calculated based on the assumptions in Table 4.03 and the results are shown in Table 4.04. The CO<sub>2</sub> emissions shown in Table 4.03 include the direct boiler emissions (118,834 g/mmBtu) of bagasse; residual oil emissions include emissions from an industrial boiler (85,045 g/mmBtu) and direct WTT residual oil use in the boiler. CO<sub>2</sub> is credited to the ethanol production process resulting from biomass (bagasse) burning.

Table 4.03 Process Shares and Emission Factors (EF) for Ethanol Production

| EtOH Production Equipment and Fuel Used                        | % Shares of Equip. Usage | CO <sub>2</sub> EF (g/mmBtu of fuel burned) | VOC EF | CO EF | CH <sub>4</sub> EF | N <sub>2</sub> O EF | Assumed % of Fuels used at the EtOH Plant | Direct Energy Use (Btu/gal) |
|--|--------------------------|---|--------|-------|--------------------|---------------------|---|-----------------------------|
| Small industrial boiler (10-100mmBtu/hr input) to burn bagasse | 100%                     | 118,834                                     | 5.34   | 76.8  | 31.6               | 4.2                 | 99.65%                                    | 83,132                      |
| Residual oil industrial boiler                                 | 10%                      | 85,045                                      | 0.9    | 15.8  | 3.2                | 0.4                 | 0.35%                                     | 284                         |

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Table 4.04 Calculated GHG Emissions for Ethanol Production Using CO<sub>2</sub> Factors from Table 4.03

| Calculations CO <sub>2</sub> in g/gal                             |  |        | Conversion to g/mmBtu                                 | Conversion to g- CO <sub>2</sub> e/mmBtu |
|---|--|--------|---|--|
| <b>Bagasse burning in EtOH Production</b>                         |  |        |   |  |
| CO <sub>2</sub> Small industrial boiler                           | (Direct energy use of bagasse, Btu/gal) *(118,834 g/mmBtu)*1.001/10 <sup>6</sup>             | 9,881  | 9,881 g/gal/(76,330 Btu/gal)*10 <sup>6</sup>          | 129,519                                  |
| CO <sub>2</sub> credit from bagasse burning                       | Bagasse burning = -(0.00642 tonne/gal *46.3% carbon content *2000 lbs/tonne*454 g/lbs)*44/12 | -9,897 | -9,897 g/gal/(76,330 Btu/gal)*10 <sup>6</sup>         | -129,732                                 |
| <b>EtOH Production</b>  |  |        |   |  |
| CH <sub>4</sub>   | Bagasse burning = 0.00642 tonne/gal*(31.6 g/mmBtu*12,947,318 Btu/gal/ 10 <sup>6</sup> )      | 2.634  | 2.634 g/gal/(76,330 Btu/gal)*10 <sup>6</sup> = 34.45  | 963.5                                    |
| N <sub>2</sub> O  | Bagasse burning = 0.00642 tonne/gal*(4.2g/mmBtu*12,947,318 Btu/gal/10 <sup>6</sup> )         | 0.351  | 0.351 g/gal/(76,330 Btu/gal)*10 <sup>6</sup> = 4.60   | 1,395                                    |
| <b>Residual Oil</b>   |  |        |   |  |
| CO <sub>2</sub> of small industrial boiler                        | (Direct energy use of residual oil, Btu/gal) *10%* (85,045 g/mmBtu)/10 <sup>6</sup>          | 2.1    | (2.1 g/gal) / (76,330 Btu/gal)*10 <sup>6</sup>        | 28.0                                     |
| CO <sub>2</sub> for WTT of crude oil                              | (Direct energy use of residual oil, Btu/gal) *10%* (3,260 g/mmBtu)*1/10 <sup>6</sup>         | 0.1    | (0.1 g/gal) / (76,330 Btu/gal)*10 <sup>6</sup>        | 1.1                                      |
| CO <sub>2</sub> for WTT of residual oil                           | (Direct energy use of residual oil, Btu/gal) *10%* (5,607 g/mmBtu)/10 <sup>6</sup>           | 0.1    | (0.16 g/gal) / (76,330 Btu/gal)*10 <sup>6</sup>       | 1.8                                      |
| VOC   | (Direct energy use of residual oil, Btu/gal)*(0.9 g/mmBtu)/10 <sup>6</sup>                   | <0.01  | (<0.01 g/gal)/ (76,330 Btu/gal)*(3.1)*10 <sup>6</sup> | <0.01                                    |
| CO  | (Direct energy use of residual oil, Btu/gal) * (15.8 g/mmBtu)/10 <sup>6</sup>                | <0.01  | (<0.01 g/gal)/ (76,330 Btu/gal)*(1.6)*10 <sup>6</sup> | 0.08                                     |
| <b>Total GHGs for ethanol production (gCO<sub>2</sub>e/mmBtu)</b> |  |        |   | <b>2,021</b>                             |
| <b>Total GHGs for ethanol production (gCO<sub>2</sub>e/MJ)</b>    |  |        |   | <b>1.9</b>                               |

Note: Feed Loss Factor is assumed at 1.000. Small amounts of CH<sub>4</sub> and N<sub>2</sub>O are negligible.

Carbon ratio of bagasse is 46.3% by CA-GREET default.

The 10% allocation of residual oil to ethanol is a CA-GREET default value. The 10% is to account for lubricating oil that is used not as a combustion source but is lost during the operation of the machinery involved in ethanol production. For this document, the lubricating oil is modeled as residual oil and its WTT emissions are used as a surrogate for lubricating oil. (Numbers may not add up, due to rounding)

## SECTION 5. ETHANOL TRANSPORT AND DISTRIBUTION

### 5.1 Energy for Ethanol Transportation and Distribution

For the CA-GREET sugarcane ethanol pathway modeled here, the default sugarcane ethanol transport and distribution (T&D) from Brazil to the U.S is divided as follows:

- From ethanol plant in Brazil to U.S ports:
  - Inside Brazil: 50% by rail (500 miles) and 50% by pipeline (500 miles)
  - From Brazilian ports to U.S ports by ocean tanker (7,416 miles)
- From U.S ports to distribution centers inside U.S
  - 100% by Heavy Duty Truck (100 miles)
- For distribution within U.S
  - 80% by truck (50 miles)
  - 20% directly from ports to blending terminals

Instead of calculating the WTT values on a per tonne basis as CA-GREET does for the sugarcane transport component, CA-GREET calculates WTT energy required per mmBtu of fuel (anhydrous ethanol) transported. Table 5.01 below shows the major inputs used in calculating transport energy and Table 5.02 presents the CA-GREET formulas used to calculate the ethanol transport energy for each transport mode.

*Table 5.01 Inputs and Calculated Energy Requirements for Ethanol Transport to Bulk Terminals*

| Transport                                    | Mode             | Energy Intensity (Btu/tonne-mile) | Distance from Origin to Destination (mi) | Capacity (tonnes) | Fuel Used (mi/gal) | Energy Used (Btu/mi for truck) (Btu/hp hr for ship) | Shares of Diesel Used | % Fuel Transported by Mode |
|--|------------------|-----------------------------------|--|-------------------|--------------------|---|-----------------------|----------------------------|
| Brazil Plant to Brazil port                  | Pipeline         | 253                               | 500                                      | 110               | n/a                | n/a   | 20%                   | 50%                        |
|  | Rail             | 370                               | 500                                      | n/a               | n/a                | n/a   | 100%                  | 50%                        |
| Brazil port to U.S port                      | Ocean Tanker     | 32                                | 7,416                                    | 150,000           | 19                 | 4,620   | 100%                  | 100%                       |
|  |                  | 29                                | 7,416                                    | 150,000           | 19                 | 4,691   | 100%                  | 100%                       |
| U.S port to distribution center inside U.S   | Heavy Duty Truck | 1,028                             | 100                                      | 33                | 5                  | 25,690  | 100%                  | 100%                       |
| Distribution to blending terminal inside U.S | Heavy Duty Truck | 1,028                             | 50                                       | 33                | 5                  | 25,690  | 100%                  | 80%                        |

Note: Pipeline use 20% diesel, 6% electricity, 24% natural gas, the remaining 50% is residual oil. Ocean tanker travel from origin and back has different energy consumption. For ethanol distributed in the U.S, 20% ethanol is directly transported to blending terminal by CA-GREET default.

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Table 5.02 Calculations for Ethanol Transport Energy by Transport Mode

| Transport Mode   | CA-GREET Formula   | Relevant Parameters   | Btu/mmBtu     |
|--|--|---|---------------|
| Transport Pipeline within Brazil   | - 6% electricity use:<br>$(10^6/A)*B/((g/lb)*(lb/tonne)*C)*(D)*[6%*(H)*100\%] = 440$<br>- 20% diesel use:<br>$(10^6/A)*B/((g/lb)*(lb/tonne)*C)*(D)*[20%*100%*(1+(F))] = 1,260$<br>- 50% residual oil:<br>$(10^6/A)*B/((g/lb)*(lb/tonne)*C)*(D)*[50%*100%*(1+(G))] = 3,010$<br>- 24% NG Use:<br>$10^6/A*B/((g/lb)*(lb/tonne)*C)*(D)*[24%*100%*(1+(K))] = 1,402$ | A = Ethanol LHV = 76,330 Btu/gal<br>B = Ethanol density = 2,988 g/gal<br>C = Mi traveled = 500 miles<br>D = Energy intensity = 253 (Btu/tonne-mile)<br>E = %Diesel Share = 20%<br>F = Diesel energy = 0.157 Btu/Btu<br>G = Residual oil energy = 0.106 Btu/Btu<br>H = Electricity Energy in Brazil = 1.347 Btu/Btu<br>K = NG energy = 0.073 Btu/Btu | 6,202         |
| Transport Rail within Brazil   | 100% diesel use:<br>$10^6/A*B/((g/lb)*(lb/tonne)*I)*K*[E*(1+F)]$   | I = Mi traveled = 500 miles<br>J = % Electricity share = 0%<br>K = Rail energy intensity = 370 Btu/tonne-mile   | 9,414         |
| Transport Ocean Tanker to U.S ports  | $10^6/A*B((g/lb)*(lb/tonne)*L*(M+N)*100\%(1+G))$   | L = Mi traveled = 7,416 miles<br>M = energy intensity from origin = 32 Btu/tonne-mile<br>N = energy intensity from destination = 29 Btu/tonne-mile  | 21,992        |
| <b>Total EtOH Transportation used in Brazil = 50%*6,202 + 50%*9,414 + 21,992 =</b> |  |   | <b>29,800</b> |
| Transport Within U.S   | $10^6/A*B((g/lb)*(lb/tonne)*O*(P+P)*100\%(1+F))$   | O = Mi traveled = 100 miles<br>P = energy intensity = 1,028   | 10,459        |
| <b>Total EtOH Transportation</b>   |  |   | <b>40,259</b> |
| Distribution   | $10^6/A*B((g/lb)*(lb/tonne)*Q*(P+P)*100\%(1+F)*80\%$   | Q = Mi traveled = 50 miles<br>80% = shares of truck travel  | 4,183         |
| <b>T&amp;D Total (Btu/mmBtu)</b>   |  |   | <b>44,442</b> |

Note: The energy intensity for heavy duty trucks is multiplied by 2 to account for return trip.



**5.2 GHG Calculations from Ethanol Transportation and Distribution (T&D)**

Similar to sugarcane T&D, ethanol T&D to bulk terminal is assumed in CA-GREET model by rail and pipeline inside Brazil, then ocean tanker from Brazilian ports to U.S ports, and finally from trucks to terminal within U.S. All the assumptions are the same as sugarcane T&D's and are shown in Table 5.03. The values in this table do not reflect the mode shares.

*Table 5.03 Assumptions in Calculating GHG Emissions from EtOH Transportation*

| Transport Mode        | Transport Fuel | 1-way Energy Intensity (Btu/tonne-mile) | Distance from Origin to Destination (mi) | WTT Fuel CO <sub>2</sub> Emissions of transportation fuels (g/mmBtu) | CO <sub>2</sub> Emission Factors of Diesel Combustion (g/mmBtu) |
|-----------------------|----------------|---|--|--|---|
| 50% Rail              | Diesel         | 370                                     | 500                                      | 12,647   | 77,623  |
| 50% Pipeline          | Electricity    | 253                                     | 500                                      | 18,504   | -   |
|                       | Diesel         |   |  | 12,647   | Turbine: 78,179<br>Reciprocating Engine: 77,337                 |
|                       | Residual Oil   |   |  | 8,867  | Turbine: 85,061<br>Reciprocating Engine: 84,219                 |
|                       | Natural Gas    |   |  | 5,218  | Turbine: 58,044<br>Reciprocating Engine: 56,013                 |
| 100% Ocean Tanker     | Residual Oil   | 32 (29)                                 | 7,416                                    | 8,867  | 84,102  |
| 100% Heavy Duty Truck | Diesel         | 1,713                                   | 100                                      | 12,647   | 77,809 (77,913)   |
| 80% Heavy Duty Truck  | Diesel         | 1,713                                   | 30                                       | 12,647   | 77,809 (77,913)   |

Note: It is assumed that all locomotives use diesel. Values in parenthesis are for the return trips

The results are shown in Table 5.04. The WTT emissions shown in the Table for each GHG species is calculated in the "T&D" tab of CA-GREET model. The equation for CO<sub>2</sub> from rail is shown below and the calculations for the other transport modes and GHG gases are done similarly. VOC and CO emissions are not shown in Table 5.04, which contribute 8.7 g/mmBtu and 18.6 g/mmBtu (on a CO<sub>2</sub>-equivalent basis), respectively. CA-GREET also includes 19.7 g/mmBtu VOC fugitive emissions (62 g/mmBtu CO<sub>2</sub>-equivalent). Note that only one-way rail emissions are counted, whereas an extra term exists in the calculation for truck transport to account for the return truck trip; emissions from the return trip are assumed to be equal to emissions for the trip from the origin to destination.

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Table 5.04 GHG Emissions from EtOH Transport and Distribution

| Transport Mode                                   | CO <sub>2</sub> Emissions, Excluding VOC and CO (g/mmBtu) | CH <sub>4</sub> Emissions (g/mmBtu) |                      | N <sub>2</sub> O Emissions (g/mmBtu) |                      | CO <sub>2</sub> e (g/mmBtu) |
|--|---|-------------------------------------|----------------------|--------------------------------------|----------------------|-----------------------------|
|  |   | actual                              | as CO <sub>2</sub> e | actual                               | as CO <sub>2</sub> e |                             |
| Transported by Pipeline                          | 449   | 0.77                                | 0.77*25=19           | 0.01                                 | 0.01*298=3           | 471                         |
| Transported by Rail                              | 737   | 0.83                                | 0.83*25=21           | 0.02                                 | 0.02*298=6           | 784                         |
| Transported by Ocean Tanker                      | 1,856   | 1.97                                | 1.97*25=49           | 0.04                                 | 0.04*298=12          | 1,917                       |
|  | <b>2,449*</b>   |                                     | <b>89</b>            |                                      | <b>21</b>            | <b>3,152</b>                |
| Transported by Heavy Duty Truck                  | 820   | 0.9                                 | 23                   | 0.02                                 | 6                    | 859                         |
| Distributed by Heavy Duty Truck                  | 328   | 0.2                                 | 5                    | 0.00                                 | 1                    | 334                         |
| Total  | <b>3,597</b>  |                                     | <b>107</b>           |                                      | <b>28</b>            | <b>4,345</b>                |
| <b>Total GHG Emissions (gCO<sub>2</sub>e/MJ)</b> |   |                                     |                      |                                      |                      | <b>4.1</b>                  |

Note: \*In Brazil, assumed 50% EtOH transportation travel by rail and 50% by pipeline

Note: Anhydrous ethanol modeled here is not suitable for use in blending with the CARBOB component to produce California Reformulated Gasoline (CaRFG). Calculations pertaining to tailpipe emissions from the use of denatured ethanol blended with CARBOB (to produce CaRFG) are detailed in the CaRFG document and is available on the Low Carbon Fuel Standard website ([www.arb.ca.gov/fuels/lcfs/lcfs.htm](http://www.arb.ca.gov/fuels/lcfs/lcfs.htm)).

## **APPENDIX A2 (SCENARIOS 1 AND 2)**

**SCENARIO 1: MECHANIZED HARVESTING AND  
ELECTRICITY CO-PRODUCT CREDIT**

**SCENARIO 2: ELECTRICITY CO-PRODUCT CREDIT**

## Detailed calculations for the two additional scenarios analyzed for Brazilian sugarcane ethanol

This appendix details the calculations for the two additional scenarios presented in the summary section of this document. They include:

Scenario 1: Mechanized harvesting and export of co-product power from plant burning bagasse

Scenario 2: Export of co-product power from plants burning bagasse

Table A2 provides a comparison of the two scenarios with the baseline pathway completed in February 2009 and detailed in Appendix A1. All of the assumptions for the two scenarios are the same as those for the baseline pathway (except for the variations considered in the two scenarios).

*Table A2 Comparison of Baseline Pathway with Two Additional Scenarios Analyzed In This Appendix*

| Pathway  | Baseline Pathway | Scenario 1   | Scenario 2   |
|--|------------------|--------------|--------------|
| Mechanized Harvest                               | No               | Yes          | No           |
| With Co-Product Electricity Credit               | No               | Yes          | Yes          |
| <b>Total GHG Emissions (gCO<sub>2</sub>e/MJ)</b> | <b>27.40</b>     | <b>12.20</b> | <b>20.40</b> |

### Scenario 1: Mechanized harvesting and export of co-product electricity from plant burning bagasse

The dominant practice of cane harvest in Brazil has been burning the straw prior to harvesting. This practice however is gradually being replaced by mechanized harvesting and new regulations prohibit burning prior to harvesting in Sao Paulo, Brazil by 2012 (the largest state in Brazil producing and importing sugarcane ethanol to the U.S)<sup>5</sup>.

The baseline pathway calculated that burning generated 8.2 gCO<sub>2</sub>e/MJ of GHG emissions (details provided later in this Appendix). When a mechanized process is adopted, the baseline pathway is credited with this amount to provide a WTW emissions for the pathway with mechanized harvesting. For the co-product electricity, a GHG credit of 7.0 gCO<sub>2</sub>e/MJ is applied (details provided later in this Appendix). Therefore, this scenario has a total WTW of **12.20 gCO<sub>2</sub>e/MJ** (baseline of 27.4 – 8.2 – 7.0).

<sup>5</sup> Sao Paulo State Law: 11.241 on 19 September 2002

**Scenario 2: Export of co-product electricity from plants burning bagasse**

As indicated in Scenario 1, the co-product credit is 7.0 gCO<sub>2</sub>e/MJ which leads to WTW emissions for this scenario of **20.40 gCO<sub>2</sub>e/MJ** (baseline of 27.4 – 7.0). A complete detail of the co-product credit is provided later in this Appendix.

**Detailed CA-GREET model calculations of values used for scenarios 1 and 2**

**SECTION 1. GHG EMISSIONS FROM AVOIDING STRAW BURNING AND MECHANIZED HARVESTING OF SUGARCANE**

As mechanization replaces field burning prior to harvesting by hand, the avoided emissions are calculated and presented as an emissions credit to the pathway. Section 1.3 in Appendix A1 presented details of the emissions from straw burning prior to harvest and the results are shown here in Table 1.01

*Table 1.01 Avoided Emissions from Mechanized Harvesting*

| <b>Emission Species</b>                          | <b>GHG Emissions (gCO<sub>2</sub>e/MJ)</b> |
|--|--|
| VOC  | 2.2  |
| CO   | 14.4                                       |
| CH <sub>4</sub>                                  | 6.6  |
| N <sub>2</sub> O                                 | 2.1  |
| CO <sub>2</sub>                                  | 163.2                                      |
| Biogenic CO <sub>2</sub> Credit                  | (-180.2)                                   |
| <b>Total GHG Emissions (gCO<sub>2</sub>e/MJ)</b> | <b>8.2</b>                                 |

**SECTION 2. GHG EMISSIONS ACCOUNTING FOR CO-PRODUCT CREDIT FROM ELECTRICITY GENERATION**

Data was supplied to staff by the Brazilian Sugarcane Association (UNICA) for 39 plants that produce excess electric power using energy from burning of bagasse. The exported electricity is assumed to displace power from new generation, which in Brazil is natural gas derived. Table 2.02 summarizes the data from UNICA<sup>6</sup>.

<sup>6</sup> Data and Personal Communication with Joel Valesco and associates (UNICA) on 06/30/2009

Table 2.02 Total Electricity Exported to Grid in 2008 in Brazil of 39 Mills Surveyed

| Ethanol Mills | Cane Crushed (tonnes) | Surplus Electricity Exported (MWh) | Average Surplus Electricity (kWh/tonne) |
|---------------|-----------------------|------------------------------------|---|
| 39            | 121,694,215           | 3,062,304                          | <b>25.16</b>                            |

The CA-GREET model uses a default co-product electricity value of 0.96 kWh/gal for the export electricity scenario. This value is equal to **23.1** kWh/tonne cane which is close to the actual value. For the calculations provided below, this CA-GREET default value of **23.1** kwh/tonne cane has been used.

Assumptions: (CA-GREET)<sup>7</sup>

Thermal energy of sugarcane: 1,188 MJ/tonne

LHV of bagasse: 12,947,318 Btu/ton

Bagasse moisture content: 50%

Biomass boiler efficiency: 80%

Power generation efficiency: 30%

Energy needed per gallon of cane ethanol:

$$\frac{1188 \text{ MJ / tonnecane}}{1055 \text{ MJ / MMBtu}} \times \frac{1}{80\%} \times \frac{1 \text{ tonnecane}}{24 \text{ galEtOH}} = 58,546 \text{ Btu/gal ethanol}$$

Bagasse Energy yield per gallon of Ethanol:

$$\frac{12,947,318 \text{ Btu / ton}}{10^6} \times \frac{1055 \text{ MJ}}{1 \text{ MMBtu}} \times \frac{1}{(2000 \text{ lb / ton}) \times (0.454 \text{ kg / lb})} \times 50\% \times \frac{280 \text{ kgbagass / 1000kgcane}}{0.024 \text{ gal / kgcane}}$$

= 83,124 Btu/gal ethanol

Extra bagasse Btu for Electricity Co-gen:

$$\frac{(83124 \text{ Btu / gal} - 58546 \text{ Btu / gal}) \times 30\%}{3412 \text{ Btu / KWh}} = 2.16 \text{ kWh / gal}$$

After internal deduction 1.2 kWh/gal from ethanol processing (0.5 kWh/gal electrical and 0.7 kWh/gal mechanical usage), the extra electricity export from bagasse is (2.16 - 0.5 - 0.7) kWh/gal = **0.96 kWh/gal**

The results are a CA-GREET calculation based on the electricity exported and the emission factor in the CA-GREET model for marginal natural gas based power generation. The first column in Table 1.03 is a CA-GREET calculation for Brazil marginal power in the EtOH sheet. The adjacent column calculates the co-product credit in g/gal with subsequent columns showing the unit conversions to g/MJ. Table 2.03 shows the results for co-product electricity credit (-7.0 gCO<sub>2</sub>e/MJ) as calculated in CA-GREET.

<sup>7</sup> Using data from M. Wang et al: WTW Energy Use and GHG Emissions of Brazilian Sugarcane Ethanol - July 2007

Table 2.03 GHG Emissions for Co-product Electricity Credit

|                                       | <b>Brazil<br/>Marginal<br/>Electricity<br/>(Btu/mmBtu,<br/>g/mmBtu)</b> | <b>Co-Product<br/>Electricity<br/>Credit<br/>(Btu/gal, g/gal)</b> | <b>Co-Product<br/>Electricity<br/>Credit<br/>(Btu/mmBtu,<br/>g/mmBtu)</b> | <b>Co-Product<br/>Electricity<br/>Credit<br/>(J/MJ, g/MJ)</b> |
|---------------------------------------|---|---|---|---|
| Total energy                          | 2,984,567   | -8,981  | -117,666  | -117,666  |
| VOC                                   | 25.859  | -0.078  | -1.018  | -0.001  |
| CO                                    | 97.830  | -0.294  | -3.847  | -0.004  |
| CH <sub>4</sub>                       | 368.782   | -1.110  | -14.544   | -0.014  |
| N <sub>2</sub> O                      | 3.624   | -0.011  | -0.143  | 0.000   |
| CO <sub>2</sub>                       | 176,859   | <b>-532</b>   | -6,972  | -6.6  |
| CO <sub>2</sub> (incl. VOC and<br>CO) | 177100  | -533  | -6,982  | -6.6  |
| <b>Total GHG</b>                      | <b>187,399</b>  | <b>-564</b>   | <b>-7,388</b>   | <b>-7.0</b>   |

The calculations for the electricity credit are based on the product of the co-product power and the emission intensity of the electricity in g/mmBtu.

#### Sample Calculation for CO<sub>2</sub>:

Electricity Fuel Shares = 0.96 kWh \* 3,412 Btu/kWh = 3,276 Btu/gallon.  
 3,276 Btu/gallon \* 176,859 g/mmBtu/10<sup>6</sup> Btu = **532** g/gal (see entry in Table 1.03).

## **APPENDIX B**

### **INPUT VALUES FOR ETHANOL FROM BRAZILIAN SUGARCANE**



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**Scenario: Ethanol made in Brazil from Brazil Sugarcane and transported to California.**

| Parameters                                       | Units     | Values | Note                                  |
|--|-----------|--------|---------------------------------------|
| <b>GHG Equivalent</b>                            |           |        |                                       |
| CO <sub>2</sub>                                  |           | 1      | CA-GREET Default                      |
| CH <sub>4</sub>                                  |           | 25     | CA-GREET Default                      |
| N <sub>2</sub> O                                 |           | 298    | CA-GREET Default                      |
| VOC  |           | 3.1    | CA-GREET Default                      |
| CO   |           | 1.6    | CA-GREET Default                      |
| <b>Sugarcane Cultivation</b>                     |           |        |                                       |
| <b>Fuel Use Shares</b>                           |           |        |                                       |
| <i>Diesel</i>                                    |           | 38.3%  | CA-GREET Default                      |
| <i>Gasoline</i>                                  |           | 12.3%  | CA-GREET Default                      |
| <i>Natural Gas</i>                               |           | 21.5%  | CA-GREET Default                      |
| <i>LPG</i>                                       |           | 18.8%  | CA-GREET Default                      |
| <i>Electricity</i>                               |           | 9%     | CA-GREET Default                      |
| <b>Cultivation Equipment Shares</b>              |           |        |                                       |
| <i>Diesel Farming Tractor</i>                    |           | 80%    | CA-GREET Default                      |
| <i>CO<sub>2</sub> Emission Factor</i>            | g/mmBtu   | 77,411 | CA-GREET Default                      |
| <i>Diesel Engine</i>                             |           | 20%    | CA-GREET Default                      |
| <i>CO<sub>2</sub> Emission Factor</i>            | g/mmBtu   | 77,349 | CA-GREET Default                      |
| <i>Gasoline Farming Tractor</i>                  |           | 80%    | CA-GREET Default                      |
| <i>CO<sub>2</sub> Emission Factor</i>            | g/mmBtu   | 75,645 | CA-GREET Default                      |
| <i>NG Engine</i>                                 |           | 100%   | CA-GREET Default                      |
| <i>CO<sub>2</sub> Emission Factor</i>            | g/mmBtu   | 57,732 | CA-GREET Default                      |
| <i>LPG Commercial Boiler</i>                     |           | 100%   | CA-GREET Default                      |
| <i>CO<sub>2</sub> Emission Factor</i>            | g/mmBtu   | 68,036 | CA-GREET Default                      |
| <b>Sugarcane Farming</b>                         |           |        |                                       |
| <i>Sugarcane energy use</i>                      | Btu/tonne | 41,592 | CA-GREET Default                      |
| <i>Sugarcane harvest yield</i>                   | tonne/ha  | 75     | CA-GREET Default                      |
| <b>Sugarcane T&amp;D</b>                         |           |        |                                       |
| <i>Transported from Sugarcane Field to Stack</i> |           |        |                                       |
| <i>by medium truck</i>                           | miles     | 10     | 2,199 Btu/mile-tonne Energy Intensity |
| <i>fuel consumption</i>                          | mi/gal    | 7.3    | capacity 8 tonnes/trip                |
| <i>CO<sub>2</sub> emission factor</i>            | g/mi      | 1,369  | CA-GREET Default                      |
| <i>Transported from Stack to EtOH Plant</i>      |           |        |                                       |
| <i>by heavy duty diesel truck</i>                | miles     | 40     | 1,713 Btu/mile-tonne Energy Intensity |
| <i>fuel consumption</i>                          | mi/gal    | 5      | capacity 15 tonnes/trip               |
| <i>CO<sub>2</sub> emission factor</i>            | g/mi      | 1,999  | CA-GREET Default                      |
| <b>Chemicals Inputs</b>                          |           |        |                                       |
| <b>Nitrogen</b>                                  |           |        |                                       |
| <i>NH<sub>3</sub></i>                            | g/tonne   | 1,092  | CA-GREET Default                      |
| <i>Production Efficiency</i>                     |           |        |                                       |
| <i>Production Efficiency</i>                     |           | 82.4%  | CA-GREET Default                      |
| <i>Shares in Nitrogen Production</i>             |           | 70.7%  | CA-GREET Default                      |
| <i>CO<sub>2</sub> Emission Factor</i>            | g/g       | 2.475  | CA-GREET Default                      |
| <i>Urea</i>                                      |           |        |                                       |
| <i>Production Efficiency</i>                     |           | 46.7%  | CA-GREET Default                      |
| <i>Shares in Nitrogen Production</i>             |           | 21.1%  | CA-GREET Default                      |
| <i>Ammonium Nitrate</i>                          |           |        |                                       |
| <i>Production Efficiency</i>                     |           | 35%    | CA-GREET Default                      |
| <i>Shares in Nitrogen Production</i>             |           | 8%     | CA-GREET Default                      |
|  |           |        |                                       |
|  |           |        |                                       |

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| Parameters   | Units                     | Values                 | Note  |
|--|---------------------------|------------------------|---|
| <b>P<sub>2</sub>O<sub>5</sub></b>                      | g/tonne                   | 149                    | CA-GREET Default  |
| <b>H<sub>2</sub>SO<sub>4</sub></b>                     |                           |                        |   |
| <i>Feedstock input</i>                                 | tonnes                    | 2.674                  | CA-GREET Default  |
| <b>Phosphor Rock</b>                                   |                           |                        |   |
| <i>Feedstock input</i>                                 | tonnes                    | 3.525                  | CA-GREET Default  |
| <b>K<sub>2</sub>O</b>                                  | g/tonne                   | 193.6                  | CA-GREET Default  |
| <b>CaCO<sub>3</sub></b>                                | g/tonne                   | 5,337.7                | CA-GREET Default  |
| <b>Herbicide</b>                                       | g/tonne                   | 8.1                    | CA-GREET Default  |
| <b>Pesticide</b>                                       | g/tonne                   | 2.21                   | CA-GREET Default  |
| <b>CO<sub>2</sub> from CaCO<sub>3</sub> use</b>        | g/tonne                   | 2,349                  | CA-GREET Default  |
| <b>Sugarcane Straw Burning Credit</b>                  | g/tonne                   | -349,067               | CA-GREET Default  |
| <b>EtOH Production</b>                                 |                           |                        |   |
| <b>Yield</b>   |                           |                        |   |
| <i>EtOH Yiel</i>                                       | gal/wet tonne             | 24.0                   | CA-GREET Default  |
| <i>Sugarcane Straw Yield</i>                           | Dry tonne/tonne sugarcane | 0.14                   | CA-GREET Calculations   |
| <i>Bagasse Burning/gal EtOH Yield</i>                  | Dry tonne/gal             | 0.00642                | CA-GREET Default  |
| <b>Production</b>                                      |                           |                        |   |
| <i>Energy use for Sugarcane Mill EtOH</i>              | Btu/gal                   | 251                    | CA-GREET Default  |
| <i>From Residual Oil</i>                               |                           | 0.3%                   | CA-GREET Default  |
| <i>Residual Oil Industrial Boiler</i>                  | g/mmBtu                   | 85,045                 | CA-GREET Default  |
| <i>From Bagasse burning</i>                            |                           | 99.7%                  | CA-GREET Default  |
| <i>Bagasse –burned, small Industrial Boiler</i>        | g/mmBtu                   | 118,834                | CA-GREET Default  |
| <b>EtOH T&amp;D</b>                                    |                           |                        |   |
| <i>Transported by rail – inside Brazil</i>             | miles                     | 500                    | 370 Btu/mile-tonne Energy Intensity, CA-GREET Default                 |
| <i>Transported by pipeline – inside Brazil</i>         | miles                     | 500                    | 253 Btu/mile-tonne Energy Intensity, CA-GREET Default                 |
| <i>Transported by Ocean Tanker to U.S.</i>             | miles                     | 7,416                  | 26 Btu/mile-tonne Energy Intensity from original, CA-GREET Default    |
| <i>From U.S. back to Brazil</i>                        | miles                     | 7,416                  | 39 Btu/mile-tonne Energy Intensity from destination, CA-GREET Default |
| <i>Transported by HHD truck to distribution center</i> | miles                     | 100                    | 1,028 Btu/mile-tonne Energy Intensity both ways, CA-GREET Default     |
| <i>Transported by HHD truck to blending terminal</i>   | Miles                     | 50                     | 1,028 Btu/mile-tonne Energy Intensity both ways, CA-GREET Default     |
| <b>Fuels Properties</b>                                |                           |                        |   |
|  | <b>LHV (Btu/gal)</b>      | <b>Density (g/gal)</b> |   |
| <i>Crude</i>   | 129,670                   | 3,205                  | CA-GREET Default  |
| <i>Residual Oil</i>                                    | 140,353                   | 3,752                  | CA-GREET Default  |
| <i>Conventional Diesel</i>                             | 128,450                   | 3,167                  | CA-GREET Default  |
| <i>Conventional Gasoline</i>                           | 116,090                   | 2,819                  | CA-GREET Default  |
| <i>CaRFG</i>   | 111,289                   | 2,828                  | CA-GREET Default  |
| <i>CARBOB</i>  | 113,300                   | 2,767                  | CA-GREET Default  |
| <i>Natural Gas</i>                                     | 83,868                    | 2,651                  | As liquid   |
| <i>EtOH</i>  | 76,330                    | 2,988                  | Anhydrous ethanol (neat)  |
| <i>EtOH</i>  | 77,254                    | 2,983                  | Denatured ethanol (2.5% by volume)                                    |
| <i>Bagasse (Btu/dry tonne)</i>                         | 12,947,318                | n/a                    | CA-GREET Default  |