1 Summary

1.1 California GREET Model Pathway

A Well-To-Tank (WTT) fuel cycle analysis of the Caribbean Basin Initiative (CBI) ethanol dehydrators' sugarcane to ethanol pathway includes all steps from sugarcane farming in Brazil to dehydrated ethanol for use in the US. Tank-to-wheel (TTW) analysis includes actual combustion of fuel in a motor vehicle for motive power. Together, WTT and TTW analysis are combined 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) developed by Argonne National Laboratory has been used to calculate the energy use and greenhouse gas (GHG) emissions generated during the entire process starting from farming sugarcane to producing and combusting ethanol in an internal combustion engine. Life Cycle Associates, with assistance from ARB modified the original GREET model to create a California specific model termed the CA-GREET model. Changes were restricted mostly to input factors (emission factors, generation mix, transportation distances, etc.) with no substantial changes in methodology inherent in the original GREET model. This California modified GREET model (v1.8b, released December 2009) forms the basis of this document. It has been used to calculate the energy use and Greenhouse Gas (GHG) emissions associated with a WTW analysis for sugarcane ethanol produced in Brazil for use in light duty vehicles in California.

The CBI ethanol dehydrators use hydrous ethanol sourced from Brazil and dehydrate the ethanol to 99.5% purity. This dehydrated ethanol is then transported to the United States for blending and use.

The pathway described here includes ocean transport of hydrous ethanol to a Caribbean nation, dehydration in a Caribbean nation and ocean transport of anhydrous ethanol to California. Sugarcane farming, ethanol production and fuel use is unchanged from the sugarcane to ethanol pathway provided by ARB.

Most of the basic inputs, assumptions, and calculation methodology used in this analysis are provided in the sugarcane to ethanol technical document from ARB[1]. The modifications to the CA-GREET include the use of California specific factors (e.g. renewable diesel production, vehicle combustion, etc.). Additional factors that have been modified for California for the use of fuels such as electricity, natural gas, etc. within the state are detailed in companion documents that have been published on the Low Carbon Fuel Standard website.

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[1] ARB (2009) 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, Version 2.3, California Air Resources Board, Stationary Source Division, September 2009. http://www.arb.ca.gov/fuels/lcfs/092309lcfs_cane_etoh.pdf

To summarize, the pathway documented here includes transportation of hydrous ethanol to a Caribbean nation. The ethanol is then dehydrated to anhydrous ethanol and transported to CA. Figure 1 below shows the discrete components that form the sugarcane ethanol pathway including farming, transport of sugarcane, ethanol production, and transport and distribution to refueling stations and final use in a transportation vehicle. The specific processes examined in this document are shaded in Figure 1.

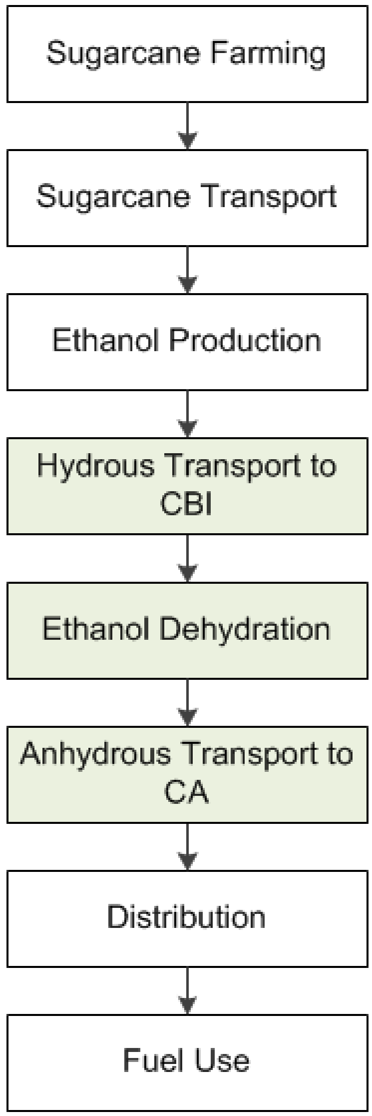

Figure 1. Discrete Components of the Sugarcane to Ethanol Pathway

This document provides detailed calculations, assumptions, inputs and other necessary information to calculate the energy requirements and GHG emissions for the modifications to the Brazilian sugarcane to ethanol pathway.

2 Caribbean Basin Initiative Ethanol Dehydration

The Caribbean Basin Initiative (CBI) ethanol dehydrators provided data to justify the calculation of their WTW carbon intensity. Farming of the sugarcane and production of hydrous ethanol occur before transportation to the Caribbean for dehydration. Distribution, blending, and fuel use occurs after the dehydrated ethanol is transported to California. These steps are explained in the ARB Brazilian sugarcane ethanol pathway technical document and are not included in this discussion.

Life Cycle Associates surveyed a total of six ethanol dehydration plants to determine energy use during the process as well as transportation emissions. Each is applying for a separate carbon intensity and pathway. This report shows the results for Jamaica Broilers Ethanol. The location of dehydration plant included in this study is shown in Table 1. All of these plants use molecular sieve technology to break the ethanol-water azeotrope, so no denaturants are added during the distillation process. These dehydration plants use a mix of fuel oil No. 6 and electricity to dehydrate ethanol from 95% ethanol to 99.5% ethanol.

Table 1. Jamaica Broilers Ethanol Dehydrator and Location

Ethanol Dehydrator	Location
Jamaica Broilers Group	Port Esquivel, Jamaica

The calculations presented here show the additional energy used during ethanol dehydration, increased transport weight for shipping hydrous ethanol, and distance added for ocean transport to a Caribbean nation.

2.1 Emissions from Residual Oil Production

The total fuel cycle of residual oil includes crude oil extraction, refining, and distribution. The life cycle emissions are calculated in the CA-GREET model. The total life cycle GHG emissions are calculation in Table 2. Life cycle inventory data are calculated based on the U.S. average regional selection in the CA GREET model, the same as that used for the Brazil sugarcane ethanol pathway. The total life cycle GHG emissions for residual oil include the sum of the crude oil, refinery phase, and residual oil combustion.

Table 2. Life Cycle Inventory for Residual Oil

Pollutant	Crude Oil	Residual Oil Refining	Idustrial Boiler	Fuel Oil WTT + Fuel Combustion
Energy (Btu/mmBtu)				
Total energy	39,212	74,239	1,000,000	1,113,451
Fossil fuels	37,778	73,322	1,000,000	1,111,100
Coal	7,133	12,408	0	19,541
Natural gas	17,654	22,003	0	39,658
Petroleum	12,990	38,911	1,000,000	1,051,901
Emissions (g/mmBtu)				0
VOC	4.189	2.822	0.907	7.917
CO	11.680	4.507	15.764	31.951
CH4	90.166	4.944	3.240	98.350
N2O	0.065	0.054	0.360	0.479
CO2	3,836	5,597	85,045	94,478
CO2 (inc. VOC and CO)	3,868	5,613	85,072	94,553
GHG (g/mmBtu)	6,141	5,752	85,261	97,154
GHG (gCO_2e/MJ)	5.8	5.5	80.8	92.1
GREET Cells	Petroleum! B183:B196	Petroleum! J183:J196	EF!J6:J14	Sum

Loss factor = 1.000000

2.2 Ethanol Dehydration

The ethanol dehydration facilities use fuel oil No. 6 and electricity as the only energy inputs to their processes. To calculate the GHG emissions, data gathered from each dehydrator were combined with GREET default values. A residual oil utility boiler was used to determine the emission factors and the US Average region was assumed for the electricity resource mix.

Fuel oil usage was determined from two years of operational history. Supporting documents and operational histories are also confidential and are attached to this application. Purchase records are compared to process data report to validate the energy use for the facility per gallon of ethanol. See Attachment B for a discussion of energy use.

Energy use for the facility is ___ gal of heavy fuel oil per gallon of anhydrous ethanol plus ___ kWh/gal of electricity. The fuel oil is used to provide process heat and the electricity is used to operate pumps, fans, and controls. The electricity number includes the amount of electricity necessary to transfer the hydrous ethanol by pump from the ocean tanker to the dehydration facility and the anhydrous ethanol by pump from the dehydration facility to the ocean tanker.

Using the confidential fuel and electricity use data, the carbon intensity of the CBI ethanol dehydrators is given in Table 3 below. Energy use reflects the production of U.S. specification ethanol.

Table 3. CBI Ethanol Dehydration Carbon Intensity

	$(g\ CO_2e/MJ)$		
CBI Dehydrator	**Fuel Oil CI**	**Electricity CI**	**Dehydration CI**
Jamaica Broilers Group	5.421	0.318	5.739

2.3 Transportation of Hydrous and Anhydrous Ethanol

The transportation emissions were calculated using average distances traveled between ethanol production, dehydration and distribution terminals for each dehydration facility. These distances were determined by using the Worldwide Shipping Register located at e-ships.net. The GREET default for ocean transport from Brazil is 7,416 miles and approximates the average distance traveled from Santos, Brazil to New York, NY and Los Angeles, CA. Since the pathway proposed here is California-specific, an appropriate baseline for each transportation segment is determined.

To calculate the transportation distance for each facility, the statute mile distances from Santos, Brazil to the dehydration facility and from the dehydration facility to Long Beach, CA were determined. To this, 50% of the distances from Santos, Brazil to Paranagua, Brazil and from Long Beach, CA to San Francisco, CA were added to account for ethanol imported from and exported to ports other than the largest in each nation.

Table 4. Ocean Transport Distances for CBI Ethanol Dehydrators

Ocean Transport Distances	Nautical Miles	Statute Miles
Jamaica Broilers Group		
Santos, Brazil to Port Esquivel, Jamaica	4296	4944
Paranagua, Brazil to Santos, Brazil	155	178
Port Esquivel, Jamaica to Long Beach, CA	3496	4023
Long Beach, CA to San Francisco, CA	369	425
Santos, Brazil to Long Beach, CA	7384	8497
Brazil to Port Esquivel, Jamaica	4373.5	5033
Port Esquivel, Jamaica to California	3680.5	4235
Brazil to California (via Jamaica)	8054	9268
Brazil to California (Direct)	7646	8799
Difference	408	470
Anhydrous Share	54.3%	54.3%

The baseline route was determined by taking the distance directly from Santos, Brazil to Long Beach, CA and adding the intra-nation travel distances as explained above. This calculation only computes the carbon intensity that is generated from the increase in mileage from the direct ocean transport route. A summary of the transportation distances used for each dehydration facility is shown in Table 4.

The transportation segment between Brazil and the Caribbean nation involves the transport of 95% hydrous ethanol, instead of 99.5% anhydrous ethanol. Because of this, a larger volume of ethanol is transported in this segment. The anhydrous yield, MJ anhydrous/MJ hydrous ethanol is calculated to be 0.95/0.995 = 0.9548. This effectively increases the intensity of this transport segment by 4.7%.

The summary of results for these transport calculations are shown in Table 5.

Table 5. Ocean Transport Results for CBI Dehydrators

	Mileage Difference		
CBI Dehydrator	**Hydrous Distance**	**Anhydrous Distance**	**Transport CI (g CO_2e/MJ)**
Jamaica Broilers Group	214.6	255.0	0.117

Documentation supporting the distances and shipping methods are provided separate confidential attachments. These include certification and inspection forms provided by companies such as SGS as well as bills of lading for the ocean tankers.

2.4 Process Carbon Intensity and Justifying Calculations

The final carbon intensity for the dehydration and increased transport to a Caribbean nation is summarized for each CBI ethanol dehydrator in Table 6 below.

Table 6. Process Carbon Intensity for CBI Ethanol Dehydrators

	(g CO_2e/MJ)		
CBI Dehydrator	**Transport CI**	**Dehydration CI**	**Total CI**
Jamaica Broilers Group	0.117	5.76	5.86

The inputs for this analysis are based upon the values shown by the input sheet in Table 7. The calculations and methods are similar to those used in the ARB sugarcane ethanol pathway document and are shown using a matrix of specific energies in Table 8. The calculation details for the ocean transport carbon intensities are shown in Table 9. The transport energy inputs for the hydrous ethanol are adjusted by the cargo factor to reflect the water that is hauled along with the ethanol.

The CI for ethanol transport is added to the CI for Brazil sugarcane ethanol pathways. The documentation of the sourcing of the ethanol is proposed via a sourcing worksheet presented in Attachment A. This worksheet provides brokers or third party certifiers the framework to document the Brazilian sugar mill as well as the bill of lading for the hydrous ethanol processed by the dehydration facility.

Table 7. Input Sheet for the CBI Sugarcane Ethanol

Ethanol Dehydration				
Yield	Parameter	Units		
Anhydrous yield	0.955	kg anhydrous/kg hydrous		
Energy Use	Parameter	Units	gal HFO/gal	
Residual Oil		Btu/gal		
Natural Gas	0	Btu/gal		
Electricity		kWh/gal		
Co-produced Power	Parameter	Units		
Electricity	0.0000	kWh/gal		
Ethanol Transport and Distribution				
Transport Segment	Mode	Capacity (tonnes)	Distance (mi)	Share
Hydrous Ethanol	Ocean Tanker	150,000	215	100.0%
Anhydrous Ethanol	Ocean Tanker	150,000	255	100.0%

Disclaimer[2]

[2] This report was prepared by Life Cycle Associates, LLC for Jamaica Broilers Ethanol. Life Cycle Associates is not liable to any third parties who might make use of this work. No warranty or representation, express or implied, is made with respect to the accuracy, completeness, and/or usefulness of information contained in this report. Finally, no liability is assumed with respect to the use of, or for damages resulting from the use of, any information, method or process disclosed in this report. In accepting this report, the reader agrees to these terms.

Table 8. Calculation Details for CBI Ethanol Dehydrators

Pathway Component	Fuel Dehydration		Transport	
Process	Residual Oil Boiler	Electricity	Ocean Tanker (Hydrous EtOH)	Ocean Tanker (Anhydrous EtOH)
Process Loss Factor				
Cumulative Loss Factor per Fuel Pathway Component	1.00050	1.00050	1.00050	1.00050
Feedstock Use Factor	1.00	1.00		
Units				
Process Specific Energy				
Units	Btu RO/gal EtOH	Btue/gal		
Specific Energy				
Units	mmBtu RO/mmBtu EtOH	mmBtue/mmBtu EtOH		
Fuel Cycle Energy (Btu) Total	6,679	5,341	657	745
Fossil fuels	6,540	5,341	655	743
Coal	1,150	0	12	13
Natural gas	2,335	5,320	23	27
Petroleum	3,055	21	620	704
Fuel Cycle Emissions (g) VOC	0.466	0.040	0.052	0.059
CO	1.881	0.167	0.122	0.138
CH_4	5.790	0.660	0.059	0.067
N_2O	0.028	0.006	0.001	0.001
CO_2	5,562	316	55	63
CO_2 (Incl. VOC and CO)	5,566	317	56	63
Total Fuel Cycle GHG Emissions (g CO_2e/mmBtu)	**5,719**	**335**	**58**	**65**
Total Fuel Cycle GHG Emissions (g CO_2e/MJ)	**5.421**	**0.318**	**0.055**	**0.062**

LCI Data Vectors

Fuel Pathway Component	Residual Oil Boiler	Electricity	Ocean Tanker (Hydrous EtOH)	Ocean Tanker (Anhydrous EtOH)
Denominator Units	mmBtu RO	mmBtue	mmBtu EtOH	mmBtu EtOH
Fuel Cycle Energy (Btu) Total	113,451	2,985,493	657	745
Fossil fuels	111,100	2,985,493	655	743
Coal	19,541	238	12	13
Natural gas	39,658	2,973,782	23	27
Petroleum	51,901	11,474	620	704
Fuel Cycle Emissions (g) VOC	8	23	0	0
CO	32	94	0	0
CH_4	98	369	0	0
N_2O	0	4	0	0
CO_2	94,478	176,888	55	63
CO_2 (Incl. VOC and CO)	94,553	177,105	56	63
LCI Vector Region:	US	NG Power	US	US
GREET Data Source:	Petroleum! B183-B196 Petroleum! J183-J196 EF! J6-J14			

Table 9. Calculation Details for Ocean Transport Calculations

	Transportation Mode	Ocean Tanker	
	Region	US	US
	Cargo	Hydrous EtOH	Anhydrous EtOH
	Fuel	Residual Oil	Residual Oil
	Capacity (Tons as received)	150,000	150,000
	Marine Energy Requirement (HP)	24,220	24,220
	Ocean Tanker Average Speed (mi/hr)	18.52	18.52
Origin to Destination:	Load Factor (%)	80%	80%
	Energy Consumption (Btu/hphr)	4,620	4,620
Back-Haul:	Load Factor (%)	70%	70%
	Energy Consumption (Btu/hphr)	4,691	4,691
	Feedstock Moisture Content (%)		
	Capacity Factor	0.955	1
	Distance (mi)	215	255
Fuel Economy (mi/gal):	Origin to Destination		
	Back-Haul		
Energy Use (Btu/mi):	Origin to Destination		
	Back-Haul		
Energy Intensity (Btu/ton mi):	Origin to Destination	32.2	32
	Back-Haul	29	29
	Denominator Unit:	mmBtu	mmBtu
Vehicle Energy and Emissions (Btu/unit and g/unit)			
Total energy		590	669
Fossil energy		590	669
Coal		0	0
Natural gas		0	0
Petroleum		590	669
VOC		0.048	0.055
CO		0.112	0.127
CH4		0.003	0.003
N2O		0.001	0.001
CO2		50	57
Upstream Energy and Emissions (Btu/unit and g/unit)			
Total energy		67	76
Fossil energy		66	74
Coal		12	13
Natural gas		23	27
Petroleum		31	35
VOC		0.004	0.005
CO		0.010	0.011
CH4		0.056	0.064
N2O		0.000	0.000
CO2		6	6
Total Energy and Emissions (Btu/unit and g/unit)			
Total energy		657	745
Fossil energy		655	743
Coal		12	13
Natural gas		23	27
Petroleum		620	704
VOC		0.052	0.059
CO		0.122	0.138
CH4		0.059	0.067
N2O		0.001	0.001
CO2		55	63
CO2 (including VOC and CO)		56	63
GREET Model Source		T&D!G107:G132	

Attachment A: Example Ethanol Sourcing Validation

CBI ethanol

Ethanol Sourcing Validation

1) Ethanol Plant Validation

Ethanol plant	State	Municipality	Mechanized Harvesting?	Electricity Co-generation?
Virálcool Açúcar e Álcool Ltda.	SP	Pitangueiras	Yes (100%)	Yes (capacity of export 18 MWh)

Delivered by Brazilian producer and Received by Ocean Tanker

Quantity	Vessel name	B/L Date
2661.168 cbm @ 20 deg C	Chemstar Yasu	May 14th, 2009

Official Stamp	Signature

2) CBI Dehydration

Delivered by Ocean Tanker and Received by Dehydrator

Quantity	Vessel name	Arrival Date
2,658.832 cbm @ 20 deg C	Chemstar Yasu	May 27th, 2009

Delivered by Dehydrator and Received by Ocean Tanker

Quantity	Vessel name	B/L Date
2,526.856 cbm @ 20 deg C	Sichem Manila	June 27th, 2009

Official Stamp	Signature

3) USA Import

Delivered by Ocean Tanker and Received by CA Distributor

Quantity	Vessel name	Arrival Date
2,519.275 cbm @ 20 deg C	Sichem Manila	July 04th, 2009

Official Stamp	Signature

Attachment B: Confidential Fuel Use Numbers

The fuel use numbers for each dehydration facility, as well as the level of documentation provided for these estimates is shown in the table below. For electricity use, a two-year daily operational history was difficult to produce. Since fuel oil use predominates the economics of these facilities, the electricity use numbers that are available only on a monthly basis at best. The fuel use history for each process is attached as a supplementary document to this application.

CBI Dehydrator	Fuel Oil (gal HFO/gal ethanol)	Fuel Oil (Btu/gal)	Electricity (kWh/gal)
Jamaica Broilers Group			