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.

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

[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

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refueling stations and final use in a transportation vehicle. The specific processes examined in this document are shaded in Figure 1.

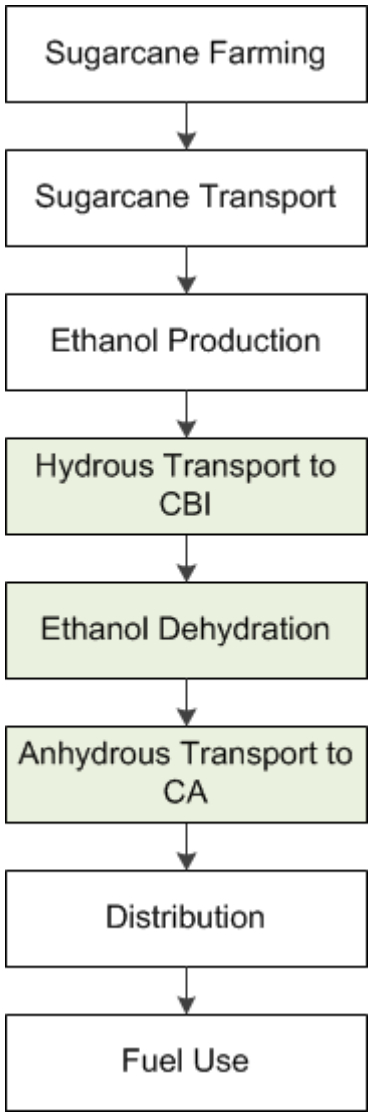

Figure 1. Discrete Components of the Sugarcane to Ethanol Pathway

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.

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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 the Gasohol El Salvador Ethanol plant. 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. Gasohol Ethanol Dehydrator and Location

Ethanol Dehydrator	Location
Gasohol Vitol	Acajutla, El Salvador

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

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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 a two-year operational history. Supporting documents and two-year operational histories are also confidential and are attached to this application. These data best represent the ongoing operation of the plant.

Energy use for the facility is fuel oil No. 6 and 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. Note that the energy required for pumping is a small fraction of the total power used at the facility.

Electric powered pumps transfer ethanol to the tanker ships. This energy is included in the total for plant operation. The energy required is a small fraction of total power. Assuming a head loss of 30 meters (100ft) the pumping energy per liter of ethanol,
$E = m \times g \times h/\text{pump efficiency}$ becomes $0.79\ \text{kg/L} \times 9.8\ \text{m/s/s} \times 30\ \text{m}/\ 0.85 = 273\ \text{J/L}$

273/3.7854 L/gal /1000 = 1.03 kJ/gal
1.03 kWs/3600 s/h = 0.00028 kWh/gal

which is less than 100th of the total electric power usage at the facility.

Using the confidential fuel and electricity use data provided to ARB, the carbon intensity of the CBI ethanol dehydrators is given in Table 3 below

Table 3. CBI Ethanol Dehydration Carbon Intensity

	CI (g CO_2e/MJ)		
CBI Dehydrator	**Fuel Oil**	**Electricity**	**Dehydration**
Gasohol Vitol	5.383	0.316	5.699

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.

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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.

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.

Table 4. Ocean Transport Distances for CBI Ethanol Dehydrators

Ocean Transport Distances	Nautical Miles	Statute Miles
Grupo Casa (ARFS), Gasohol El Salvador		
Santos, Brazil to Acajutla, El Salvador	5302	6101
Paranagua, Brazil to Santos, Brazil	155	178
Acajutla, El Salvador to Long Beach, CA	2112	2430
Long Beach, CA to San Francisco, CA	369	425
Brazil to Acajutla, El Salvador	5379.5	6191
Acajutla, El Salvador to California	2296.5	2643
Brazil to California (via El Salvador)	7676	8833
Brazil to California (Direct)	7646	8799
Difference	30	35
Anhydrous Share	70.1%	70.1%

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)**
Gasohol Vitol	10.3	24.2	0.009

Documentation supporting the distances and shipping methods are provided in forms such as Appendix A, which will be provided to document the type of sugarcane ethanol that is produced in Brazil.

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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**
Gasohol Vitol	0.009	5.699	5.71

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.

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	Confidential	Btu/gal	0.0318
Natural Gas	0	Btu/gal	
Electricity	Confidential	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	10.3	100.0%
Anhydrous Ethanol	Ocean Tanker	150,000	24.2	100.0%

Disclaimer[2]

[2] This report was prepared by Life Cycle Associates, LLC for Vitol. 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.

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Table 8. Calculation Details for CBI Ethanol Dehydrators

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	6,632	5,301	32	71
Fossil fuels	6,495	5,301	31	71
Coal	1,142	0	1	1
Natural gas	2,318	5,280	1	3
Petroleum	3,034	20	30	67
Fuel Cycle Emissions (g) VOC	0.463	0.040	0.003	0.006
CO	1.868	0.166	0.006	0.013
CH_4	5.750	0.655	0.003	0.006
N_2O	0.028	0.006	0.000	0.000
CO_2	5,523	314	3	6
CO_2 (Incl. VOC and CO)	5,528	314	3	6
Total Fuel Cycle GHG Emissions (g CO_2e/mmBtu)	**5,680**	**333**	**3**	**6**
Total Fuel Cycle GHG Emissions (g CO_2e/MJ)	**5.383**	**0.3154**	**0.003**	**0.006**

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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	

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Attachment A: 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

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Attachment B: Confidential Fuel Use Data

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.

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