Brazilian Modified GREET Pathway for the Production of Ethanol from Sugarcane - Method 2B: "Pathway for Brazilian Sugarcane Ethanol from molasses, considering specifics mechanization level inputs and co-generation export credit from ABENGOA"

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1. Pathway Summary

This lifecycle analysis calculates the Carbon Intensity (CI) of the molasses-based ethanol production from in ABENGOA (Abengoa Bioenergia Agroindústria Ltda.) which is located in the city of Pirassununga, São Paulo, Brazil.
The Carbon Intensity (CI) obtained for this pathway is **8,92** grams of CO_2-equivalent greenhouse gas emissions per mega joule (g CO_2e/MJ) of ethanol produced on an anhydrous basis. When emissions associated with land use change conversion are included, the total CI is **54,92** g CO_2e/MJ.

[redacted]

Default parameters associated with the Brazilian Sugarcane-to-Ethanol LCFS pathway (ARB Pathway) are claimed and inputs values provided by ABENGOA have been applied. Therefore, ABENGOA process is considered a By Product Molasses - to - Ethanol pathway following Method 2B guidelines.

The production of raw sugar from sugarcane juice yields molasses as feedstock. Molasses is transferred to an ethanol distillery where it is converted into ethanol through molasses fermentation followed by distillation and dehydration processes when anhydrous is produced. The finished product is shipped to California (USA) by ocean tanker.

The sugarcane cultivation, sugarcane transport, ethanol production, and finished fuel transport portions of this pathway are essentially identical to the corresponding steps in the Brazilian Sugarcane-to-Ethanol Pathway. Emissions associated with the production of the molasses feedstock are disaggregated from the emissions associated with the production of raw sugar. The energy consumption and greenhouse gas (GHG) generation are appropriately allocated between the molasses byproduct and sugar. The bulk of this pathway document, therefore, focuses on molasses production.

The Well-to-Tank (WTT) portion of this Life Cycle Analysis of ABENGOA molasses-to-ethanol pathway includes all steps from sugarcane farming to final finished anhydrous ethanol. The Tank-to Wheels (TTW) portion includes actual combustion of the resulting fuel in a motor vehicle for motive power. Taken together, the WTT and the TTW analyses comprise a total Well-to-Wheel (WTW) analysis.

The CA_GREET model was used to calculate the entire fuel life cycle, from sugarcane farming to producing ethanol to combusting ethanol in an internal combustion engine. The results obtained from the California-Modified GREET model (v1.8b, released December 2009) are reported in this document. Those results consist of the energy use and greenhouse gas (GHG) emissions from the production of ethanol using molasses as feedstock. This pathway assumes that the ethanol produced is destined for use in motor vehicle fuels. ABENGOA has followed the *"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".*

2. ABENGOA Process Configuration

Abengoa Bioenergia Agroindústria Ltda facility located in Pirassununga, São Paulo, Brazil, started operation on 1981. ABENGOA is a domestic producer of sugarcane ethanol with a renewable fuel production capacity (baseline volume) of [redacted] **gal EtOH/year**.

Sugarcane fields are located on a [redacted] miles radius from the renewable fuel production facility. The production of sugarcane per hectare is [redacted] **ton/ha.**

The process begins with the transport of sugarcane to the mill, carried in trucks that are heavy on electronic scales. Then, the trucks are weighted and sampled for sugar content analysis, after that the sugarcane is unloaded. The unloaded sugarcane is conveyed for milling in a 6 stage cascaded in counter flow with the juice. The facility has a nominal capacity of processing [redacted] **ton/day of sugarcane.** The juice is drained and separated from the bagasse. The juices are heated and pH corrected and transferred into a tank for gravity sedimentation. The facility produces [redacted] **gal/h of purified juice**. The purified juice is pumped to the sugar production plant. The facility produces purified molasses, as co-product of sugar production and consumes [redacted] **ton/day of purified molasses** to produce ethanol. Water is added to purified molasses, producing the mixture which is pumped to the ethanol production plant. At

the ethanol plant yeast are added to the fermenters (if necessary). After fermentation, the resulting crude wine is first separated in a series of centrifuges. The wet yeast will be used in new fermentation, after suffering a suitable chemical treatment. The separated wine is then sent to two distinct distillation stills trains. One distillation train will produce hydrated ethanol at [redacted] % weight basis and the other train will produce anhydrous ethanol at [redacted] % [redacted] The volume of ethanol produced per ton of sugarcane is [redacted]**gallons/metric ton of cane.**

The distillation bottom is acidic water named vinegar water. This vinegar water is them cool at room temperature and pumped to a centralized system for soil fertilization proposes. Bagasse is the fuel for process heating. High pressure steam is used to generate electricity and in the steam driven motors. Low pressure steam is used for process heating. The excess bagasse is stored in piles outside of the plant. The sludge from the juice decanter and from the sugarcane primary washing are concentrated and used as composite soil fertilizer.

The facility has 2 boilers and the bagasse is the only fuel for process heating. Bagasse is burned and water is heated for steam generation. The generators are moved with steam for electricity production and turbines are moved by the steam generated in the process. The steam is then used to run the distillery. High pressure steam is used to generate electricity. Low pressure steam is used for process heating. To generate electricity, the plant has 3 generators.
ABENGOA has now a total nominal capacity of [redacted] MW, generating at the time of sugarcane crushing [redacted] MW and consuming [redacted] MW, resulting in an export potency of [redacted] MW approx.

Figure 1 describes ABENGOA molasses-to-ethanol process:

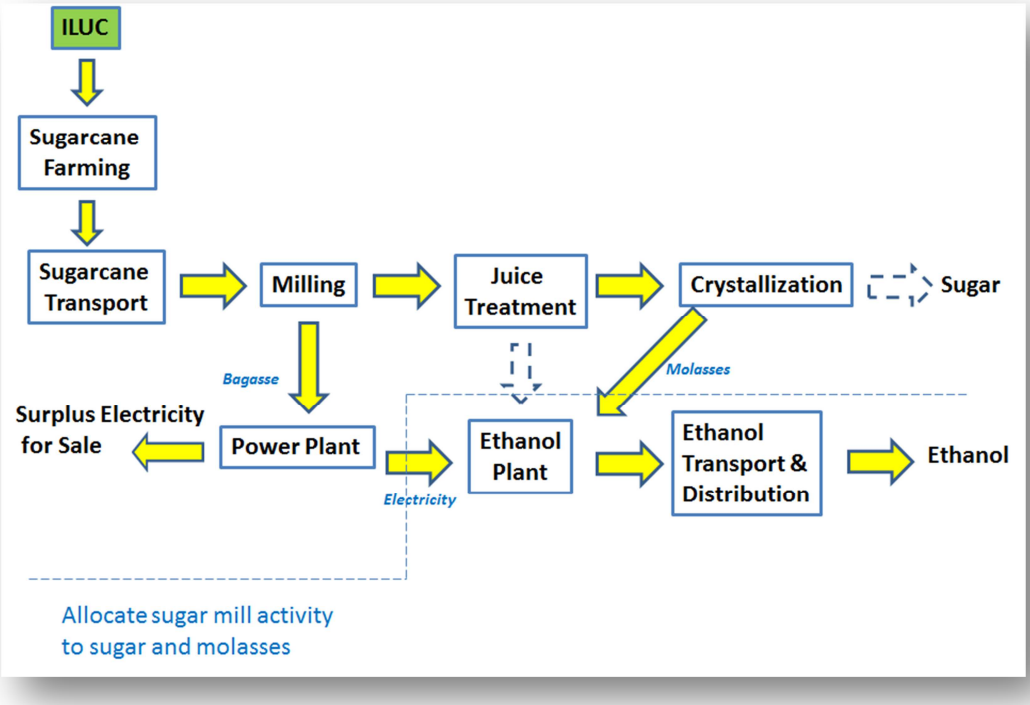

Figure 1: Simplified ABENGOA molasses-to-ethanol process

3. Allocation of GHG Emissions between Sugar and Molasses

3.1. Allocation procedure:

The life cycle analysis tracks the energy inputs and emissions according to the value of the sugar that is converted to granular sugar and the sugar that is converted to molasses. ABENGOA tracks the molasses according to its sugar content, so the allocation procedure is straightforward.

The allocation step subtracts the emissions that are associated only with the production of final raw sugar (which is not an ethanol feedstock) from the ethanol production totals. The ***agricultural and sugar production emissions*** that are allocated to the ethanol feedstock (molasses) are added to ***the emissions from the production and transport and distribution of ethanol.*** The result is the total life cycle emissions value for ethanol made from molasses.

3.2. Methodology applied:

The Mass Based Allocation Methodology has been applied. This methodology determines the "Allocation Factor" to be applied in the procedure explained above. The AF is defined as the fraction of sucrose that doesn`t end up in final raw sugar, i.e, that ends up in molasses.

The allocation factor (AF) has been obtained as follows:

Parameter	Values	Calculated as:	Units
ηj (cane crushing yield)	[redacted]	Value provided by ABENGOA. This fraction represents the sucrose fraction per ton of cane.	Tons of fermentable sugars in juice / Ton of cane
ηs (raw sugar manufacturing efficiency)	[redacted]	Value provided by ABENGOA. This fraction represents the sucrose yield.	Tons of sucrose in final sugar / Ton of sucrose into factory
Sucrose in Molasses	[redacted]	ηj * (1- ηs)	Tons sucrose in molasses / Tons of sugarcane
AF	[redacted]	(1- ηs)	Tons sucrose in molasses feedstock / Tons sucrose in cane juice

Table 1: Allocation Factor Determination

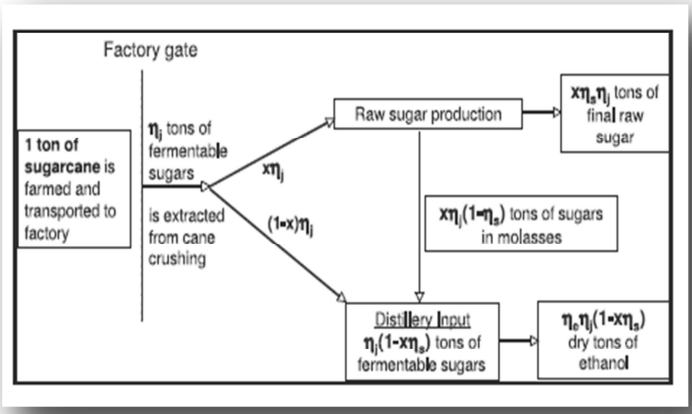

Figure 2: Mass and Process Flow of an Integrated Sugar and Ethanol Factory[1]

Where:

x = fraction of cane juice sent to manufacture raw sugar;

η_j = cane crushing yield (tons of fermentable sugars in juice/ton of cane);

η_s = raw sugar manufacturing efficiency (tons of sucrose in final sugar/ton of sucrose in);

η_e = ethanol distillery efficiency (dry tons EtOH/ton of sucrose in).

[1] *"Molasses for ethanol: the economic and environmental impacts of a new pathway for the lifecycle greenhouse gas analysis of sugarcane ethanol".* Anand R Gopal and Daniel M Kammen. 2009.

ABENGOA process is molasses-based pathway in which the molasses used to produce ethanol is considered as a feedstock product or a molasses not exhausted of its sucrose content, i.e., a product of higher quality, rich in TRS[2]. Therefore, ABENGOA is not likely to benefit from a lower indirect land use change (ILUC) estimate and an ILUC of 46 g CO2e/MJ (default value provided by GREET) will be applicable to ABENGOA's molasses-based ethanol pathway.

Once the GHG emissions allocation methodology was defined, the following disaggregated emissions table was obtained. Table 2 summarizes the energy used and GHGs emitted from each stage in the production of ethanol from molasses. In this analysis, the carbon intensity of sugarcane ethanol is calculated by considering all the incremental emissions that occur from farming through the production of ethanol. Land use change emissions are also included, as well as the emissions from adding a denaturant. The resulting carbon intensity of the sugarcane-molasses-to-ethanol pathway is **54,92 g CO2e/MJ.**

[2] TRS: Total Reduced Sugars

Disaggregated Item	Value Reference	GHG Emissions: Sugarcane to Ethanol (gCO_2e/MJ)	Allocated GHG Emissions: Sugarcane to Ethanol (gCO_2e/MJ)
Well -to-Tank (WTT)		***Allocation Factor***	***0,26***
Sugarcane Farming	"Sugarcane Farming"	15,82	4,17
Agricultural Chemicals Production	"Sugarcane Farming"	33,88	8,93
Straw Burning	"Straw Burning"	31,68	8,35
- Less Credit for Mechanized Harvesting (1)	"Straw Burning"	(22,95)	(6,05)
Sugarcane Transport	"T&D"	7,76	2,04
Sugarcane Material Handling and Supplemental Fuel Use	"EtOH"	5,86	1,54
Sugar Production	"Allocation" & "Sugarcane Farming"	8,35	2,20
Lime (CaO) Use for Juice pH Adjustment		-	0,60
Ethanol Production	"EtOH"	-	2,40
Ethanol Transport & Distribution	"T&D"	-	4,74
Denaturant (2)	"Indonesian Molasses Pathway"	-	0,80
Well-to-Tank (WTT) Estimate Before Electricity Export Credit		-	***29,73***
Electricity Cogeneration and Export Credit	"Cogeneration"	(78,94)	(20,81)
Total Well-to-Tank (WTT) CI Estimate:		-	***8,92***
Tank-to-Wheels (TTW)			
Land Use Change (4)	"Allocation" based on Brazil LUC Estimate.		46,00
Final Well-to-Wheel (WTW) Estimate:			***54,92***

Table 2: Summary of Well-To-Wheel Emissions for Sugarcane to Ethanol

The emissions allocations shown in Table 2 are calculated as described previously. Note that the values in the Sugarcane Farming, Agricultural Chemicals Production, Straw Burning, Sugarcane Transport, and Sugar Production rows are all allocated from the totals in the pre-allocation *"GHG Emissions: Sugarcane to Ethanol"* column. The values from the Ethanol Production, Ethanol Transport and Distribution and Denaturant rows, are however, equal in the two columns (allocated versus pre-allocated GHG Emissions).

4. Supporting Data and Calculations

4.1 Farming, Agricultural Inputs and Sugarcane Transport

ABENGOA has used default values for Sugarcane Farming and Agricultural Inputs.

Energy inputs for Sugarcane Transport are based on transport distance and truck capacity. ABENGOA provided the transportation distances for the cane supply. The average distance is [redacted] miles compared to the GREET default of [redacted] miles.

4.2 Straw Burning

Emissions from sugarcane straw burnt in field are based on ABENGOA summary of mechanical and manual harvesting and other default values provided by the GREET model. The sugarcane is [redacted] % mechanically harvested (value calculated performing the average of the last three years: 2012, 2013 and 2014). GIS shape files were provided for CARB data analysis.

4.3 Co-product electricity value

ABENGOA has provided actual data to support co-product electricity credit value, generating [redacted] KWh/ tons of cane crushed as 2013.

ABENGOA has a system of generating electricity with an installed capacity of [redacted] MW through 2 (two) [redacted] MW generators and 1 (one) [redacted] MW generator. With the burning of cane bagasse in boilers of [redacted] kgf/cm² and [redacted] °C it propitiated steam for the operation of its industrial plant.

The plant has also a kit motor and power generator (STEMAC) of [redacted] kV for emergencies.

4.4 Ethanol Transport

Transportation from the Mill to Brazilian Port is assumed by diesel trucks with a distance of [redacted] miles and the mode of transport from the Brazilian Port to Los Angeles (USA) Port is assumed to be by Ocean Tanker (using Residual Oil as fuel) over a distance of [redacted] nautical miles.

4.5 Changes to default input variables in the CA-GREET Lifecycle Analysis Model

PARAMETER	DEFAULT VALUE	NEW VALUE
Miles from Farm to Mill	12	[redacted]
Miles from Mill to Port	50	[redacted]
Nautical Miles from Port to Port	7.416	[redacted]
Miles in US for Fuel Transportation	100	[redacted]
KWh /galEtOH	-0,96	[redacted]

Sugar Cane Farming Energy Use (Btu/tonne)	41.592	[redacted]
Sugar Cane EtOH Plant Energy Use (Btu/gallon)	251	[redacted]