California Environmental Protection Agency

Air Resources Board

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Low Carbon Fuel Standard (LCFS) Regulatory Guidance 16-XX

Guidance for Modeling the Carbon Intensity (CI) of Sugarcane-based Ethanol Pathways in CA-GREET 2.0 Using the Tier 1 Calculator

VERSION 1.0, June 6, 2016.

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SCOPE

This document is intended to assist alternative fuel producers or providers (referred to as "applicants" in this document) that produce ethanol fuel from sugarcane-based feedstocks such as sugarcane juice and molasses (a byproduct of the sugar production process), with the determination of a carbon intensity (CI) value for their fuel. This guidance is exclusively discusses fuel produced from the sugarcane crop most commonly grown in Brazil, and is intended to assist applicants with the calculation of the CI for ethanol fuel produced from either feedstock, or both feedstocks at an integrated sugar and ethanol production mill. The CI value is calculated using the Tier 1 Calculator of the CA-GREET 2.0 life-cycle analysis model.

I. INTRODUCTION

Sugarcane crop is a perennial crop grown that produces a juice rich in sugars which can be fermented into ethanol fuel, and a residue called bagasse that is a valuable biomass resource for the production of energy. In order to determine the lifecycle greenhouse gas (GHG) impacts associated with the production and consumption of ethanol, a Well-to-Wheels lifecycle analysis using the CA-GREET 2.0 model is performed for all aspects of ethanol fuel use; from growing and harvesting of the sugarcane crop, to transport, distribution, and final use of ethanol fuel in a vehicle.

The sugarcane crop is harvested either mechanically using mechanical harvesters which separate the tops and leaves from the cane stalk, or manually by employing pre-harvest burning practices to reduce the dense vegetation of the sugarcane crop.
Pre-harvest burning is sometimes also called straw burning. During this activity, the entire sugarcane field is intentionally set on fire. The fire burns off some of the excess vegetation (mainly the tops and leaves), and leaves the cane stalk intact. The cane is then either manually harvested or mechanically harvested after the dense vegetation has been eliminated. All harvesting that employs pre-harvest burning, for the purposes of lifecycle analysis and carbon intensity (CI) determination, is considered to be manually harvested sugarcane even if mechanical harvesters are employed to cut the cane after burning. Mechanical harvesters cut the entire crop, remove the tops and leaves, and then chop the cane stalk into pieces which are collected in a bin behind the harvester. The cut cane obtained either manually or with harvesters, is then transported to the mill in heavy-duty tractor-trailers. Currently, mechanical harvesting accounts for the majority of the sugarcane harvest practices in the premier cane-growing regions of Brazil today. If mechanical harvesting is employed, then the fraction of the sugarcane that was mechanically harvested must be determined to credit the GHG impacts associated with straw burning and assessed to the ethanol pathway.

The harvested cane is transported from the field to the ethanol plant/sugar mill via heavy-duty diesel tractors (HDD) with multiple trailer beds. Upon arrival at the mill, the sugarcane is milled, then crushed to produce sugarcane juice, and a fibrous residue called bagasse. Three products can be derived from sugarcane juice namely finished or table sugar for human consumption, molasses; a byproduct of the sugar production process which could be fermented or sold as a livestock supplement, and ethanol; which could be produced from direct fermentation of either pure cane juice or byproduct molasses. Most integrated mills produce finished sugar, ethanol from byproduct molasses, as well as ethanol from pure cane juice by direct fermentation. The proportion of products may vary from mill to mill, as some mills cater exclusively to the production of finished sugar and ethanol from byproduct molasses, while some mills direct a majority of the sugarcane juice feedstock to the ethanol distillery. At other times, market prices, and demand may dictate how much finished sugar or ethanol is produced from each feedstock.

At most sugarcane mills in Brazil, the sugarcane juice is first adjusted for pH and then clarified. A portion of the sugarcane juice that is extracted from the decanter is sent directly to the fermentation plant to produce ethanol. The remainder of the juice is directed to the

sugar production plant where some of the sugars in cane juice are converted into various grades of “finished sugar” (also called Very High Polarization (VHP) sugar, and Crystal sugars with high sucrose content). It is primarily the sucrose in the cane juice that is transformed into finished sugar. The remainder of the sugars in the cane juice that do not end up as finished sugar remain in byproduct molasses. The byproduct molasses while deprived of sucrose, is however rich in other fermentable sugars such as fructose and glucose, and could therefore be used as a feedstock for ethanol production. The byproduct molasses typically will not yield any further amounts of desirable finished sugars, and if it is low in fermentable sugars, it will be sold as a livestock supplement. Some producers intentionally do not “exhaust” their molasses of all its sucrose content so that they may derive a higher yield of ethanol from molasses.

The CA-GREET 2.0 Tier 1 model allows an applicant to model the GHG impacts of ethanol production using both feedstocks; sugarcane juice, as well as byproduct molasses. Additionally, energy produced and consumed, and surplus energy exported to the public grid can also be modeled in the CA-GREET 2.0 Tier 1 model. The residue bagasse generated from the sugarcane crush is combusted in a biomass boiler to produce steam for electricity generation, and steam for process requirements (thermal energy) of both the sugar and ethanol production processes. Surplus electricity is often produced in an integrated sugar and ethanol mill. This surplus electricity is exported to the public grid. When mills export their surplus cogenerated electricity, they qualify to earn a co-product credit for their pathway. Since the surplus electricity is mostly measured at the facility gate, it reflects the operations of the sugar production process, the juice-to-ethanol production process, as well as the byproduct molasses-to-ethanol production process. Therefore, the co-product credit should be appropriately allocated to the three processes: juice-to-ethanol, juice-to-sugar, and molasses-to-ethanol. Mass allocation of fermentable sugars is the most appropriate allocation methodology that can be used to apportion the total surplus electricity sold between the three products. Sugarcane processing also generates filter cake, the residue from cane juice filtration. The filter cake, which is rich in phosphorus and organic matter, has a large moisture content and may be used as a fertilizer to primarily provide nitrogen to the soil.

Ethanol production by fermentation is an anaerobic process induced by yeast that converts sucrose and other fermentable sugars present in sugarcane juice and byproduct molasses into ethanol and carbon dioxide. When sugarcane juice is sent directly to the ethanol distillery, the yield of ethanol from pure cane juice is approximately 21 gallons ethanol per metric tonne cane. With only molasses being sent to the ethanol distillery, the yield of ethanol from byproduct molasses is typically 6 to 7 gallons of ethanol per metric tonne of cane. Two grades of ethanol are produced at most mills: anhydrous ethanol, with a low moisture content, and hydrous ethanol with a modest amount of moisture. Only anhydrous ethanol is exported to California. Denaturants are added to the finished anhydrous ethanol, to limit pilferage during transport and distribution.

Sugarcane-based ethanol is transported from the ethanol plant to a domestic port by heavy-duty diesel (HDD) trucks and then loaded onto ocean-going tankers for shipment to California. Rail transportation is sometimes used for transport to an ethanol terminal from

where it could be further shipped to the port by HDD trucks. When ethanol arrives in California, HD trucks then transport ethanol from the California port to gasoline blending terminals. Once the ethanol has been blended with the gasoline, the reformulated gasoline is transported to re-fueling stations by HDD trucks.

To estimate the CI for ethanol produced from each feedstock accurately, the applicant must follow instructions (see Section II and III) to assess the GHG impacts and model the output of the ethanol mill (production). Once the output has been modeled and found to match the actual production, the parameters have been established to determine the CI for each fuel (i.e., juice-to-ethanol, and molasses-to-ethanol) pathway. Staff suggests that the applicant calculate the CI for each feedstock, and then determine whether an application should be made for the majority feedstock, or for both feedstocks (juice and byproduct molasses). The amount of ethanol that could potentially be exported to California with a particular CI value is dependent upon the modeled quantity of ethanol produced using each feedstock. This quantity is further contingent upon the amount of anhydrous ethanol produced by the mill as reported annually.

The CI determination for each feedstock begins in the “Molasses Ethanol” pathway module of the Tier 1 Calculator in the CA-GREET 2.0 model. In Section II, we will discuss the input parameters needed to model the production (sugar and ethanol output) and the corresponding CIs of the fuel pathways (i.e., pure cane juice, and molasses feedstock-based ethanol). Some inputs are specific to the mill and production process. Other inputs required are productions reports such as monthly and annual SAPCANA reports (prior two-years) filed with the Ministry of Agriculture in Brazil. In Section III, step-by-step instructions to model a pathway CI are provided using the inputs collected in Section II.

The applicant shall download a copy of the CA-GREET 2.0 Tier 1 life-cycle analysis model from the following link:

http://www.arb.ca.gov/fuels/lcfs/ca-greet/ca-greet.htm

It is advisable to have a copy of the CA-GREET Tier 1 spreadsheet open while working through the instructions in this document. The instructions will require the applicant to toggle between the “T1 Calculator” and the “EtOH” worksheets in the spreadsheet.

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II. LIST OF INPUT PARAMETERS FOR MODELING SUGARCANE-BASED ETHANOL PATHWAYS USING THE TIER 1 CALCULATOR

The following information must be collected from the mill before attempting to model the CI of the ethanol fuel produced. Most data requested should be entered as a two-year average, unless the requested data is asking for absolute transport distances, or worst-case assumptions to be conservative. For the mechanized harvesting credit, the most current harvest year records should be provided, as long as the harvest practices can be verified by remotely-sensed satellite-based observations.

a. Sugarcane Juice Shares (Juice-to-Ethanol and Juice-to-Finished or Table Sugar). Of the total tonnage of sugarcane received, the juice shares represent the percentage of juice (and hence, the percentage of cane) that is used or sent to the finished sugar factory (Cell B183 of the Tier 1 Calculator), or directly to the distillery (Cell B184). Note that these two values, when added together will equal 100%. Cell B184 is calculated by entering the value for Cell B183, and then pressing the key F9. The juice shares must be entered as a two-year average value.

b. Total Metric Tonnes of Sugarcane Crushed per Year. This is the quantity of sugarcane sourced annually from the producer's own or partnership farms, plus sugarcane purchased from external suppliers. This value is entered in Cell E212 and should represent the two-year average annual production value computed from the most recent annual SAPCANA reports.

c. The amount of surplus cogenerated electricity exported per year. This value is entered in Cell E211 (in kWh) and should represent the two-year average annual net exports leaving the plant gate and verifiable by invoices to grid electricity customers. The surplus cogenerated electricity exported should be adjusted for the amount of grid electricity purchased during periods of gestation, startup, shut down, or non-operation of the cogenerating units at the mill. Invoices for the amount of externally purchased electricity should also be provided in order to compute the net amount of surplus electricity exported to the grid. The sugarcane-based ethanol pathway modules in the CA-GREET 2.0 Tier 1 Calculator assume that all sugar and ethanol mills in Brazil will consume 0.007 kWh of grid-purchased electricity per gallon of ethanol produced.

d. Sugarcane Transport Distance from edge of the sugarcane field to the sugarcane mill (represents weighted average of estimated distance from cane supplying regions to the mill). This value is entered in Cell B214. Two additional miles (Cell B211) are added to this distance to estimate the distance associated with collection of the cane from its source location to a central collection point in the field.

e. A self-declaration of sugarcane harvest practices in spreadsheet format is required from all applicants. This document should list the name of each farm/fazenda from where sugarcane was or is being procured for sugar and ethanol production, the arable acreage of the farm, the quantity of cane procured from each farm, the harvesting period, and the type of harvest practiced at the farm; whether manual with pre-harvest

burning, or mechanized without burning (mechanically harvested sugarcane). The total acreage of mechanically harvested sugarcane is segregated from the total acreage of manually harvested sugarcane, and the mechanically harvested fraction is determined. The mechanically harvested fraction is entered in Cell B220 as a composite percentage, and should be a value that has been corroborated with remotely-sensed satellite imagery for the most recent sugarcane harvest season. See requirement (l) below, and consult with ARB staff to obtain this value.

f. η_j (eta_j, cane crushing yield) is measured in tonnes of fermentable sugars in juice per tonne of cane. In the CA-GREET model, this parameter is referred to as the amount of sucrose, but it actually represents the total amount of fermentable sugars present in cane juice that enter the finished sugar and ethanol production processes.
This parameter typically ranges from 0.11-0.15, and is disclosed by the applicant based upon their custom laboratory samples. The fermentable sugar measurement is made after the cane crush, pH adjustment, and clarification at the point where the juice enters the sugar and ethanol production processes. To accurately model the sugar and ethanol production at the mill, the value of η_j should be exclude fermentable sugar losses prior to production. This value is entered in the "EtOH" worksheet in Cell DM398.

g. η_s (eta_s, raw sugar manufacturing efficiency) is measured in tonnes of sucrose in finished sugar per tonne of sucrose ("sucrose" here is synonymous with "fermentable sugars") into sugar factory. This parameter is facility-specific, and determines the shift in production between finished sugar and ethanol. Use this value to model the shift in either sugar or ethanol production. The value is identified by the applicant at the time of the application submission process, but it may take a few iterations to get a modeled output that matches actual production averages. When a match of the modeled value is obtained, this parameter is finalized. This value is entered in the "EtOH" worksheet in Cell DM399.

h. η_e (eta_e, ethanol distillery efficiency) is measured in dry tonnes of ethanol per tonne of fermentable sugars into distillery, and is identified by the applicant during the application submission process. This parameter can assume a maximum value of 0.51, which is based on the simple stoichiometric conversion of a simple sugar molecule ($C_6H_{12}O_6$) to ethanol (C_2H_5OH) and carbon dioxide (CO_2). Use this value to model the production dry gallons of ethanol from the fermentation process. This value is entered in the "EtOH" worksheet in Cell DM401.

i. SAPCANA Annual Reports or Official Production Reports (most recent two years filed with a public agncy). In Brazil, sugar and ethanol producers file SAPCANA production reports monthly, or quarterly, and annually with the Ministério da Agricultura, Pecuária e Abastecimento. These reports will be will be utilized to estimate the annual sugarcane throughput, and model both ethanol and sugar production output with actual reported volumes to the government in the SAPCANA filings.

j. Location of the ethanol production facility (GPS coordinates). These latitude and longitude coordinates may be obtained by locating the centroid of the facility in Google Earth, or other GIS-based software.

k. Ethanol transport modes and distances from the mill (plant) to the domestic port in Brazil for shipment to California via ocean-going vessels. The transport distances are entered in the T1 Calculator worksheet in Cells E151:E160 for both sugarcane juice, as well as molasses feedstocks.

l. GIS-based shape files (harvest maps) of the sugarcane harvest areas. Boundary maps of sugarcane harvest areas from where sugarcane is sourced for sugar and ethanol production must be furnished as part of the application process. ARB will use these maps to corroborate the mechanized harvesting credit claimed in the pathway application. It is imperative that these maps be furnished in the WGS_1984 geographic coordinate projection system (GCS), and all farm boundaries be depicted as polygons, and not as free standing lines. When submitting the GIS-based sugarcane harvest maps, applicants should recognize that shape files have several associated files which are necessary for the shape file to function. These associated shape files have the *.dbf, *.shx, *.prj, and the *.shp file extensions. Without the associated shape files, the maps will not function. AutoCAD-based drawings of the sugarcane harvest maps will not substitute for the actual shape files. The shape files depicting the sugarcane harvest areas should correlate with the self-declaration of harvest practices requested in Item (e) above.

m. m_s (quality of finished sugar) is measured in tonnes of sucrose in the final sugar per tonne of final sugar product. The default value for m_s is 0.95 for VHP sugar. This value may be higher for higher quality finished sugars produced. The m_s parameter is entered in the “EtOH” worksheet in Cell DM403.

n. m_m (quality of byproduct molasses) is measured in tonnes of fermentable sugars in standard (std) molasses per tonne of standard molasses. The default value for m_m is 0.50 for 85 Brix molasses. This parameter may be higher for “rich” molasses, or lower than the default value for “exhausted” molasses. The m_m parameter is entered in the “EtOH” worksheet in Cell DM404.

o. For an integrated sugar and ethanol mill, it is important to be able to model all three products (sugar, ethanol from pure juice, and ethanol from byproduct molasses) even if the pathway CI is based upon the ethanol produced by the majority feedstock only, and a small fraction of the total amount of ethanol is produced by the minority feedstock. The modeled ethanol output (in dry gallons) is then matched to the SAPCANA adjusted dry volume of ethanol produced and reported (adjusted hydrous and anhydrous ethanol production volume).

p. A summary table of monthly surplus electricity exports for the last two-year production period. Electricity sales (in kWh per month) must be stated with the quantity sold to

each customer of the mill. This summary table must correlate to the quantities invoiced in the PDF files furnished to demonstrate surplus electricity sales to the public grid.

q. A summary table of electricity purchased from the public grid for startup and unsteady state operations at the mill. Since the Tier 1 Calculator is setup to account for only 0.007 kWh purchased per gallon of ethanol produced, surplus cogenerated electricity exported must be reduced by the purchased electricity amount in excess of 0.007 kWh per gallon. See requirement II.c above.

Section III provides detailed instructions in modeling the sugar and ethanol output produced by the mill, and the CI for the ethanol fuel produced.

III. STEP-BY-STEP MODELING INSTRUCTIONS

To model the GHG impacts of either byproduct molasses-to-ethanol, or cane juice-to-ethanol pathways, follow these steps sequentially.

1. Open the CA-GREET 2.0 Tier 1 Microsoft Excel spreadsheet. Click on the "T1 Calculator" tab.

2. For all sugarcane-based ethanol pathways, select Feedstock (Cell B7) "Molasses Ethanol," even if sugarcane Juice-to-Ethanol is the desired pathway. Click the "GO" button located on Row 7. Then, select "Feedstock Production" in Cell C8.

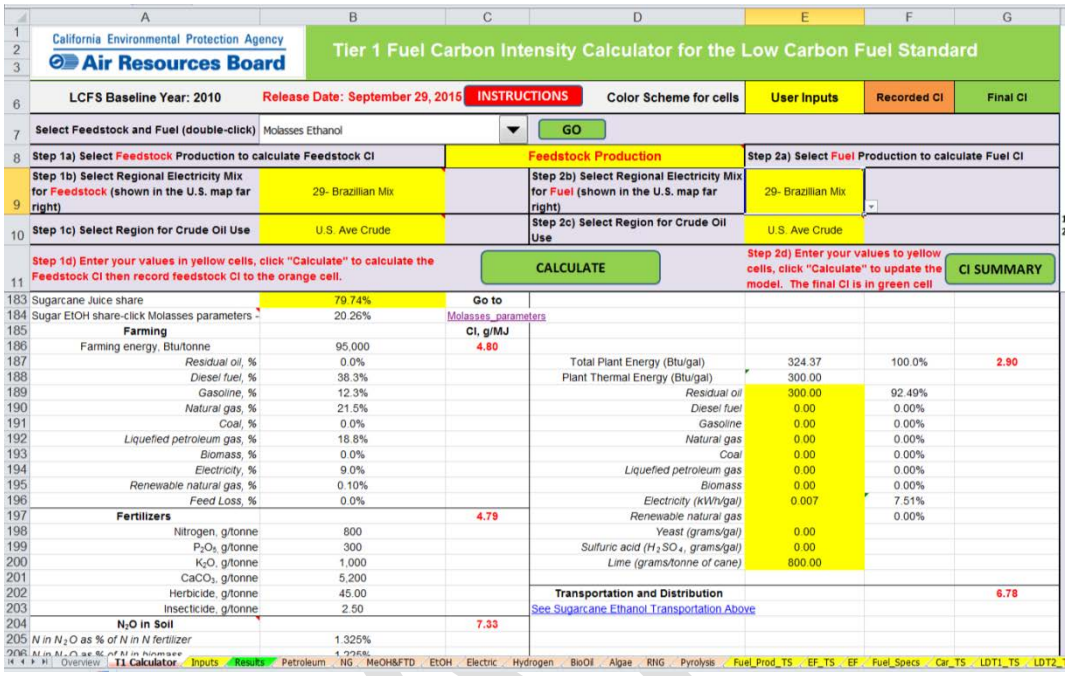
3. Set Regional Electricity Mix for both Feedstock and Fuel Production to # 29 – Brazilian Mix in Cells B9 and E9, respectively.

4. Select the Region for Crude Oil Use in Cells B10 and E10. If the Crude Mix for Brazil is Unknown, Select "U.S. Ave Crude."

5. Enter the "Juice-to-Sugar" production shares (see item Section II.a). This is the fraction of fermentable sugars in sugarcane juice allocated to the **sugar production process in Cell B183.** The sugarcane juice direct-to-ethanol production share in Cell B184 is the complement of the value in Cell B183, and is obtained by hitting either the F9 key or "Calculate" Button (located on Row 11) (see Figure 1 screenshot below). Both numbers are based upon the total average annual throughput of sugarcane crushed at the mill, and the allocation made by the mill.

6. Electricity Co-Product Credit. Select "Yes" in Cells E209 and E165 if the cogenerated electricity and surplus export co-product credit is being claimed.

Figure 1
Molasses Ethanol Module of the Tier 1 Calculator



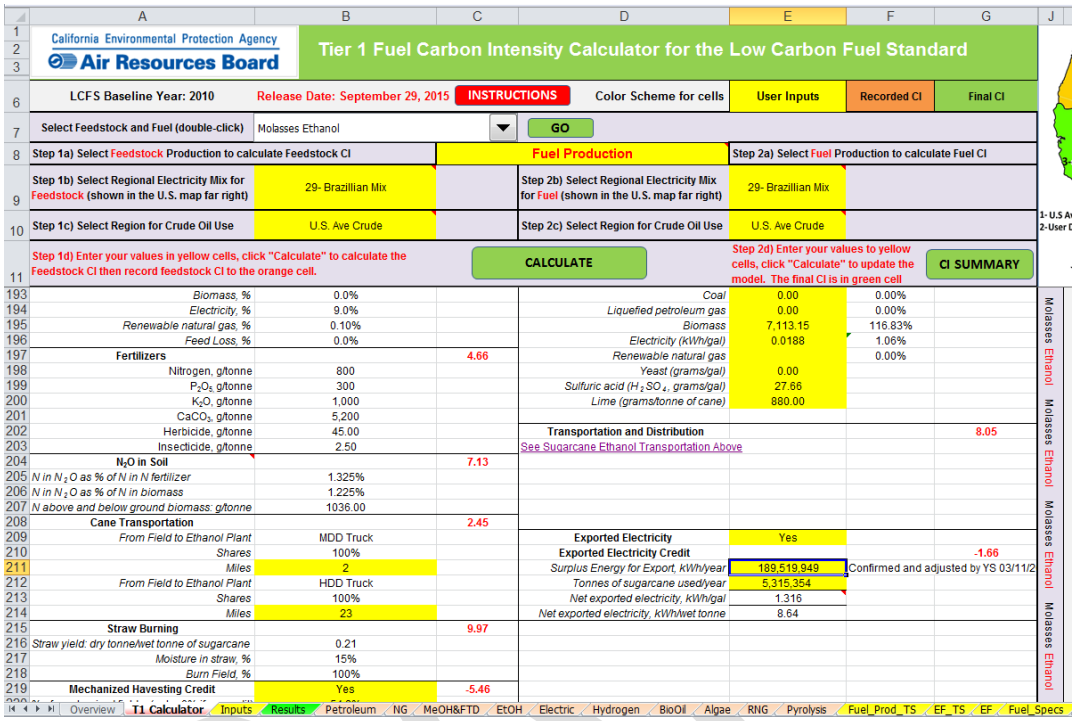
	A	B	C	D	E	F	G
1–3	California Environmental Protection Agency Air Resources Board	Tier 1 Fuel Carbon Intensity Calculator for the Low Carbon Fuel Standard					
6	LCFS Baseline Year: 2010	Release Date: September 29, 2015	INSTRUCTIONS	Color Scheme for cells	User Inputs	Recorded CI	Final CI
7	Select Feedstock and Fuel (double-click)	Molasses Ethanol	GO				
8	Step 1a) Select Feedstock Production to calculate Feedstock CI		Feedstock Production		Step 2a) Select Fuel Production to calculate Fuel CI		
9	Step 1b) Select Regional Electricity Mix for Feedstock (shown in the U.S. map far right)	29- Brazillian Mix		Step 2b) Select Regional Electricity Mix for Fuel (shown in the U.S. map far right)	29- Brazillian Mix		
10	Step 1c) Select Region for Crude Oil Use	U.S. Ave Crude		Step 2c) Select Region for Crude Oil Use	U.S. Ave Crude		
11	Step 1d) Enter your values in yellow cells, click "Calculate" to calculate the Feedstock CI then record feedstock CI to the orange cell.		CALCULATE		Step 2d) Enter your values to yellow cells, click "Calculate" to update the model. The final CI is in green cell		CI SUMMARY
183	Sugarcane Juice share	79.74%	Go to				
184	Sugar EtOH share-click Molasses parameters	20.26%	Molasses_parameters				
185	Farming		CI, g/MJ				
186	Farming energy, Btu/tonne	95,000	4.80				
187	*Residual oil, %*	0.0%		Total Plant Energy (Btu/gal)	324.37	100.0%	2.90
188	*Diesel fuel, %*	38.3%		Plant Thermal Energy (Btu/gal)	300.00		
189	*Gasoline, %*	12.3%		*Residual oil*	300.00	92.49%	
190	*Natural gas, %*	21.5%		*Diesel fuel*	0.00	0.00%	
191	*Coal, %*	0.0%		*Gasoline*	0.00	0.00%	
192	*Liquefied petroleum gas, %*	18.8%		*Natural gas*	0.00	0.00%	
193	*Biomass, %*	0.0%		*Coal*	0.00	0.00%	
194	*Electricity, %*	9.0%		*Liquefied petroleum gas*	0.00	0.00%	
195	*Renewable natural gas, %*	0.10%		*Biomass*	0.00	0.00%	
196	*Feed Loss, %*	0.0%		*Electricity (kWh/gal)*	0.007	7.51%	
197	Fertilizers		4.79	*Renewable natural gas*		0.00%	
198	Nitrogen, g/tonne	800		*Yeast (grams/gal)*	0.00		
199	P_2O_5, g/tonne	300		*Sulfuric acid (H_2SO_4, grams/gal)*	0.00		
200	K_2O, g/tonne	1,000		*Lime (grams/tonne of cane)*	800.00		
201	$CaCO_3$, g/tonne	5,200					
202	Herbicide, g/tonne	45.00		Transportation and Distribution			6.78
203	Insecticide, g/tonne	2.50		See Sugarcane Ethanol Transportation Above			
204	N_2O in Soil		7.33				
205	*N in N_2O as % of N in N fertilizer*	1.325%					
206	*N in N_2O as % of N in biomass*	1.226%					

Overview | T1 Calculator | Inputs | Results | Petroleum | NG | MeOH&FTD | EtOH | Electric | Hydrogen | BioOil | Algae | RNG | Pyrolysis | Fuel_Prod_TS | EF_TS | EF | Fuel_Specs | Car_TS | LDT1_TS | LDT2_

7. Enter the 2-Year average annual surplus cogenerated electricity exports or sales (net of grid purchased electricity in excess of 0.007 kWh per gallon) in Cell E211 (see screenshot below). This number should be based upon surplus electricity sales invoices in unit of kWh per year. In case bagasse or biomass is acquired from a source external to the sugarcane processed at the mill, the surplus cogenerated electricity should be adjusted to exclude the electricity generated from purchased bagasse. This can also be calculated with the lower heating value (LHV) of sugarcane bagasse (dry basis) times the biomass boiler efficiency times the steam turbine cogeneration efficiency to estimate the amount of steam energy or electricity generated. Consult ARB staff if bagasse is acquired from an external source.

8. Enter the total throughput of sugarcane procured or processed at the mill in Cell E212 (see screenshot below). Total annual sugarcane throughput in metric tonnes per year from the SAPCANA report should be entered in Cell E212 by summing the own (própria) production and purchased (terceiros) quantity, and then taking the 2-year average (valor).

Figure 2
Inputting Values into the Tier 1 Calculator



9. Click on the link in Cell C184 where it says “Molasses_parameters.” The link will take you to the “EtOH” worksheet. Go to Cell DO396 and verify the “Parameters for Ethanol Production” (see Section II Inputs). The Electricity Co-Product Credit rates for each pathway are calculated in Cells DR403 and DS404 based on the annual throughput of sugarcane, the annual surplus cogenerated electricity exported, and the juice shares entered previously. The electricity co-product credit for the juice-to-ethanol pathway is determined in Cell DR403. Copy-paste this value only into Cell E167 of the T1 Calculator.

Figure 3
Parameters for Ethanol Production in the EtOH! Worksheet

Parameters for Ethanol Production	Juice-to-Sugar	Juice-to-EtOH
Allocation of Sugarcane Juice	46.2%	53.8%
Surplus Energy Available for Export, kWh/year	33,920,548	
Surplus Allocated Based on TRS to Sugar and Ethanol, kWh/year	15,671,293	18,249,255
Ethanol Yield, gal/tonne cane	20.53	3.59
Tonnes of sugarcane used/year	2,018,409	
Surplus Allocated Based on TRS to Sugar and Ethanol, kWh/tonne cane	7.764	9.041
Surplus Electricity Credit before mass allocation, kWh/gal	0.378	2.518
Surplus Electricity Credit after mass allocation, kWh/gal		0.440

10. Find the ethanol production numbers for both anhydrous and hydrous ethanol from the SAPCANA reports and convert reported volumes (cubic meter) to dry gallons (this is equal to 1 - moisture content in the ethanol), and then multiply by 264.1593. Sum the anhydrous and hydrous ethanol quantities in dry gallons for each year, and then take the 2-year average. Record the actual ethanol production volume in the EtOH! worksheet Cell DO411 (blank cell). Additionally, record the total metric tonnes of finished sugar produced and reported in the SAPCANA reports in Cell DH409 (blank cell). The modeled production will be used to compare to this value.

    In case of externally purchased molasses used for ethanol production, the ethanol yield from externally purchased molasses should be backed out of the SAPCANA reported ethanol production volumes. This is because externally purchased molasses is likely to have a different lifecycle impact that the molasses produced as a byproduct of the sugar production process at the mill.

11. Next, go to cell DM398:DM404, and enter the facility specific sugarcane juice, sugar, molasses, and ethanol parameters (η_j, η_s, η_e, m_s, and m_m as discussed in Section II above) in their respective yellow cells (see Figure 4 below). These parameters are referred to as the "Gopal-Kammen Model Parameters." Based on these parameters, the dry yield of ethanol derived from sugarcane molasses, and from sugarcane juice will be determined in cells DN408:DN409, along with the yield of finished sugar in Cell DJ408 (see Figure 5 below).

    The maximum theoretical sugar-to-ethanol conversion efficiency ($\eta_{e)}$ in dry tonnes of ethanol per tonne of fermentable sugar into distillery is 0.5114, corresponding to cell DM401. Actual ethanol fermentation efficiencies may vary from 0.43-0.48.

Figure 4
Parameters for Molasses, Sugar, and Ethanol Production

Parameters for Molasses Production	
Gopal-Kammen Model Parameters	
ηj (tonnes of fermentable sugars in juice/tonne of cane)	**0.1315**
ηs (tonnes of sucrose in final sugar/tonne of sucrose into sugar factory)	**0.8251**
Sucrose in Molasses (tonnes sucrose in molasses/tonne of sugarcane)	**0.0230**
ηe (dry tonnes of EtOH/tonne of fermentable sugars into distillery)	**0.4681**
LHV of anhydrous EtOH (MMBtu/dry tonne EtOH)	**0.4500**
ms (tonnes of sucrose in final sugar/tonne of final sugar product)	**0.9939**
mm (tonnes of fermentable sugars in std molasses/tonne of std molasses)	**0.5503**

Figure 5
Yield of Finished Sugar, Standard Molasses, and Ethanol

Yield of Finished Sugar, Standard Molasses, and Ethanol					
Fraction of Sugarcane Juice Sent to Finished Sugar	Finished Sugar Yield (tons of finished sugar/ton of cane)	By-Product Molasses Yield (tons of standard molasses/ton of cane)	EtOH Yield (liters of EtOH/ton cane)	EtOH Yield (gal of EtOH/ton cane)	EtOH Yield (gal of EtOH/tonne cane)
1.0	**0.109**	**0.042**	**12.3**	**3.26**	**3.59**
0	**0.000**	**0.000**	**70.5**	**18.63**	**20.53**

In Cells DI 408:DI409, fraction 1.0 implies all juice is used for sugar production, and fraction 0.0 implies all juice is sent directly to fermentation. Correspondingly, the yield of ethanol from byproduct molasses is calculated in Cell DN408, and the yield of ethanol from pure cane juice sent directly to fermentation is calculated in Cell DN409.

12. Calculate the modeled ethanol production volume for the case where Cell DI = 1.0 (i.e., all sugarcane juice is sent to table sugar production), and the ethanol production volume for the case where Cell DI = 0.00 (i.e., all sugarcane juice is sent to ethanol fermentation). Record the volume of ethanol produced from each feedstock in Cells DO408:DO409 respectively. The ethanol volume from molasses is equal to the juice-to-sugar share (Cell DS397) times the annual sugarcane throughput (Cell DS 401) times the yield of ethanol from molasses per tonne of cane (Cell DN408). Record this value in Cell DO408. Similarly, the ethanol produced from pure juice is equal to the juice-to-ethanol share (Cell DR397) times the annual throughput of sugarcane (Cell DR401) times the yield of ethanol from pure juice (Cell DN409). Record the volume of ethanol produced from pure juice in Cell DO409. Sum the volumes of ethanol in Cells DO408 and DO409, and in Cell DO410. The sum of the ethanol produced (modeled from production) from sugarcane juice and sugarcane byproduct molasses should match the ethanol produced and reported in the SAPCANA reports, and

previously recorded in Cell DO411. If the numbers do not match, it necessitates an iterative process of adjustment of the "Gopal-Kammen Model Parameters" (cells DM398, DM399, DM401, DM403, and DM404) until the modeled volume matches the 2-year average SAPCANA reported volume (dry gallons).

Figure 6
Modeling Ethanol (dry gal) Production in the EtOH! Worksheet

EtOH Yield (gal of EtOH/tonne cane)	Ethanol Production for Each Feedstock = Yield x Total Annual Cane Throughput x Juice Share (%)	
3.59	3,899,542	dry gallons from Molasses Feedstock
20.53	19,147,880	dry gallons from Juice Feedstock
Modeled (gal):	**23,047,422**	Total Modeled Production
SAPCANA (gal):	**23,047,422**	SAPCANA Adjusted Volume (dry gallons)
	0	Difference

13. In most cases, the η_j, and m_m parameters are based on laboratory analysis, and specific to a production batch or average of many production batches. While these parameters are decidedly fixed, the applicant must ensure that these values reflect fermentable sugar content as entering the sugar or ethanol production processes. The factor η_s is use to increase or decrease finished sugar production, and increasing or decreasing its value shifts production between sugars and ethanol. Similarly, the factor η_e determines how efficiently the sugars in cane juice are being converted to ethanol.

14. Similarly, the 2-year average sugar production numbers from the SAPCANA reports (for example, production "producao" of VHP and Crystal sugars must be matched by taking the sugar yield from Cell DJ408 and multiplying the yield with the juice-to-sugar shares (Cell DS397) and the annual throughput of sugarcane entered in Cell DR401. Figure 7 below illustrates this calculation and comparison.

Figure 7
Modeling Finished Sugar Production in the EtOH! Worksheet

	Finished Sugar Production (metric tonnes)	Fraction of Sugarcane Juice Sent to Finished Sugar	Finished Sugar Yield (tons of finished sugar/ton of cane)
Modeled Production:	**118,563**	**1.0**	**0.109**
SAPCANA Reported Production:	**118,563**	**0**	**0.000**
Difference:	**0**		

15. The Molasses Yield can be found in Cell DK408. The modeled molasses production quantity can be calculated from the molasses yield times the sugarcane allocated for the production of sugar (Cell DS397 x Cell DR401). This may be matched to the "Mel Residual" quantity reported in the SAPCANA report. Staff notes that since molasses is an intermediate feedstock for the production of ethanol, it may be hard to match the molasses produced with the "Mel Residual" allocated for sales and reported in the SAPCANA report. Staff only requires that the finished sugar and total ethanol production volumes from each feedstock be matched to establish the mass allocation ratio for the pathway.

16. Once the modeled match for ethanol production from byproduct molasses, ethanol from juice, and finished sugar is made with the SAPCANA reported numbers, then the mass allocation ratio is determined in Cell DM412. This cell apportions upstream of ethanol production impacts for ethanol derived from sugarcane molasses.

17. The electricity co-product credit is calculated in Cell DS404 for the byproduct molasses-to-ethanol pathway, and in Cell DR403 for the sugarcane juice-to-ethanol pathway. Cell DR403 should be entered in E167 of the T1 Calculator or the juice-to-ethanol pathway.

18. Now go back to the T1 Calculator.

19. Input the cane transport parameters for the sugarcane molasses pathway (Cells B211 and B214 of the T1 Calculator worksheet), and percentage of mechanically harvested sugarcane fields (Cell B220); input the Filter Cake T&D distance (Cell B222) by summing the two cane transportation distances (Cells B211 and B214).

20. Find the plant thermal energy use and chemical use (Cells E189:E200) from the applicant's submission; use the residual oil (300 Btu/gal of Ethanol) and lime (880 g/tonne of sugarcane) as default input parameters; confirm the electricity use in

kWh/gal from purchased electricity invoices; confirm other energy resources use (for example, if propane fueled forklifts are employed in sugarcane handling or production).

21. Input the ethanol transportation and distribution distance by clicking the “See Sugarcane Ethanol Transportation Above” link in Cell D203; find the HDD truck distance from ethanol mill (plant) to the domestic port, and the Ocean Tanker distance from the domestic port to the ports in California (for example, provide estimated T&D distances from the mill to the Port of Santos (SP), then from Port of Santos to the California port, or the average of the distance from the Port of Santos to the Long Beach and Richmond, California ports). Ignore modes of transportation that do not apply to the pathway. For example, transportation of ethanol by rail to the ports in Brazil is rare, and pipeline transport of anhydrous ethanol to the ports is proposed for construction (but not existent today). Non-yellow cells are default input assumptions that cannot be changed.

22. Hit the “Calculate” button to obtain the CI for the “Feedstock Production.” Copy the CI for the Feedstock Production as determined in Cell C225 and paste that value in Cell C229 for the Molasses-to-Ethanol pathway. Next select “Fuel Production” in Cell D8, then hit the “Calculate” button to determine the impacts of the Fuel Production phase. The Total Well-to-Tank CI is the final CI for each of the two production phases (Feedstock and Fuel), and can be found in Cell G229.

23. If the CI for the sugarcane juice-to-ethanol pathway is desired, then select “Sugarcane EtOH w/Mech Harvesting & Power Exp” in Cell B7, Click “GO,” and enter all the input parameters needed to determine the CI for the sugarcane juice-to-ethanol pathway (see Figure 8 below). The parameters required will be identical to the parameters needed for the Molasses-to-Ethanol pathway, and may be transcribed from that section. Specifically, the yield of ethanol in Cell B131 is determined from Cell DN409 in the EtOH worksheet.

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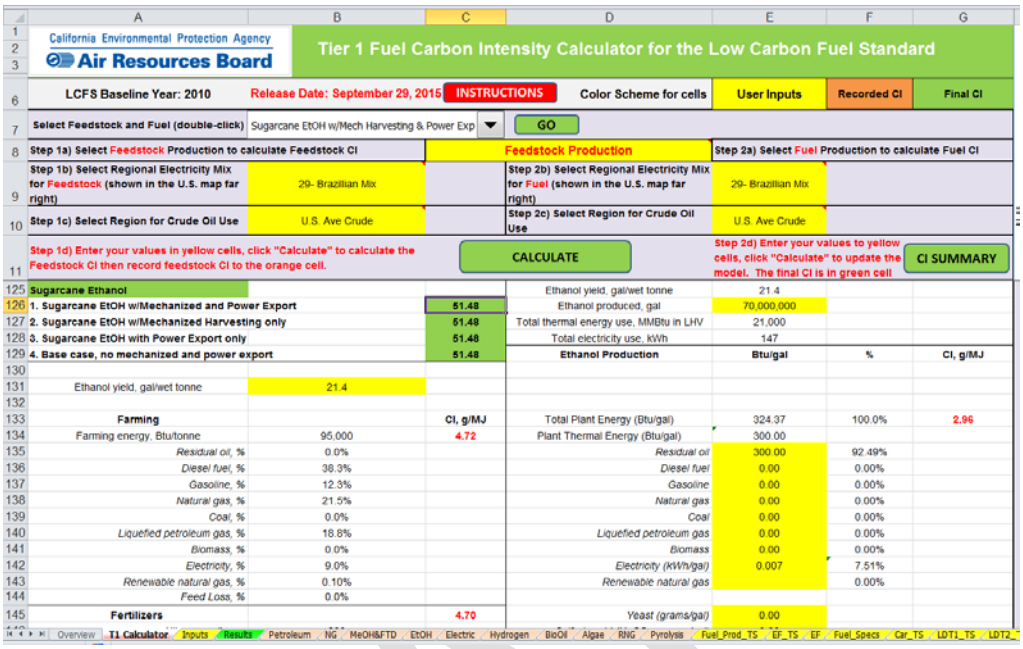
Figure 8
CI Determination for the Juice-to-Ethanol Pathway in the Tier 1 Calculator



24. The electricity co-product credit for the sugarcane juice-to-ethanol pathway is obtained from the worksheet “EtOH” in Cell DR403.

25. Once the values have been entered for the Feedstock Phase, press the “CALCULATE” button in Row 11. Record the CI value for the Feedstock Phase determined in Cell C172 in Cell C176.

26. After recording the CI for the Feedstock phase in Cell C176, change Cell C8 to “Fuel Production,” and ensure that all the input parameters for the Fuel Production phase have been inputted in the yellow cells.

27. Press the “CALCULATE” button to determine the CI for the Fuel production phase. The final CI for the sugarcane juice-to-ethanol pathway is determined in Cell G176.

28. While CIs were determined for each feedstock above, an application for pathway certification must be based on the feedstock contributing to the majority of the ethanol production. The limiting volumes for export of ethanol from either feedstock will be determined using the modeling procedure suggested above, and the reconciled values recorded in Cells DO408:409. Please note that there may be additional restrictions on the export of ethanol (such as the two-year average amount of anhydrous ethanol produced) that may over-ride the modeled ethanol production quantities from each feedstock. There may be additional requirements for export as enforcement, monitoring, and verification protocols are implemented.

After reviewing this document, if you have additional questions about sugarcane-based ethanol fuel pathway evaluations, or the CA-GREET 2.0 model, or the CI certification process, please contact:

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