Updated Sugarcane Parameters in GREET1_2012, Second Revision

Jeongwoo Han, Jennifer B. Dunn, Hao Cai, Amgad Elgowainy and Michael Q. Wang
Argonne National Laboratory
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1. Background

Brazil (producing mainly sugarcane ethanol) is the second largest producer of ethanol around the globe following the U.S. The U.S. Environmental Protection Agency (USEPA) classified sugarcane ethanol as an advanced biofuel because, during the life cycle of sugarcane ethanol, emissions of greenhouse gas (GHG) are less than 50% of the life cycle GHG emissions of baseline petroleum fuels (U.S. EPA, 2010). Moreover, the California Air Resources Board (CARB) categorized sugarcane ethanol as a low-carbon fuel through its recent analysis (CARB, 2009).

This memo describes updates to the GREET sugarcane ethanol pathway between releases GREET1_2012 rev. 0 (June 2012) and GREET1_2012 rev. 2 (December 2012). Parameters were revised related to sugarcane harvesting, handling of sugarcane ethanol plant residues, supplemental fertilizer inputs to sugarcane farming, and sugarcane ethanol transport. Several recent publications informed these revisions.

2. Harvesting and Field Burning of Sugarcane Straw

Sugarcane can be harvested manually or mechanically. Almost all manually harvested sugarcane fields are burned before manual harvesting to reduce harvesting costs and labor. On the other hand, mechanically harvested sugarcane fields can be either burned or unburned. According to Macedo et al. (2008) and Seabra et al. (2011), the fraction of mechanically-harvested fields that are unburned is rising along with the total share of fields that are unburned (Table 1) and it is expected that all mechanically harvested fields will be unburned in the near future. Therefore, GREET assumes all unburned cane is harvested mechanically and burned cane is harvested manually.

In the manually harvested (or burned) fields, field burning is a major source of GHG and air pollutant emissions in the sugarcane ethanol pathway (Tsao et al., 2012). To reduce GHG and air pollutant emissions, Brazilian federal and state governments passed legislation to phase out field burning by 2030, encouraging mechanical harvesting. The trend in the share of unburned cane harvesting area in 2002, 2005 and 2008 (Table 1) indicates that field burning has been phased out faster than the law requires. Thus, the share of unburned cane harvesting area in 2010 is increased to 40% from 35%.

Table 1 Share of unburned cane and mechanical harvesting area

	Unit	Literature Data			GREET Assumptions		
		2002[a]	2005[a]	2008[b]	2010	2015	2020
Unburned cane harvesting	% area	20%	31%	35%	40%	80%	100%
Mechanical harvesting		35%	50%	48%			

[a] Macedo et al. (2008)

[b] Seabra et al. (2011)

When sugarcane is harvested, cane residue called straw remains in the field and contributes nutrients to the soil. GREET's treatment of the fate of this straw depends on the harvesting technique used. For manually harvested, burned fields, GREET now assumes 90% rather than 75% of sugarcane straw is burned (Seabra et al. 2011). Unburned sugarcane straw (e.g. the remaining 10%) is left in the field.

Sugarcane straw from mechanically harvested (or unburned sugarcane) fields can be collected and be co-combusted with sugarcane bagasse in ethanol plants to generate electricity. Macedo et al. (2008) assumed that 40% of sugarcane straw is recovered and used to generate electricity in 2020. Previously, GREET assumed that the electricity export from sugarcane mills attributable to bagasse and straw combustion would increase from 10.7 to 25, 75 and 100 kWh/tonne cane in 2005, 2010, 2015 and 2020, respectively. Assuming the collection of sugarcane straw to fuel sugarcane ethanol plants increases from a baseline of zero in 2005 and the increased electricity export from sugarcane mills results solely from sugarcane straw (not bagasse) combustion, the shares of collected sugarcane straw are obtained as shown in Table 2.

Table 2 Time series for straw recovery and electricity co-produced with sugarcane ethanol

	Electricity export (kWh/MT cane)	Increased electricity export to 2005 (kWh/MT cane) [a]	Share of straw for electricity generation (% total straw)	Share of unburned cane harvesting area[d]	Share of straw for electricity generation (% unburned straw)[e]
2005	10.7	0	0%	35%	0%
2010	25	14.3	6.4%[b]	40%	16%
2015	75	64.3	28.8%[b]	80%	36%

2020	100	89.3	40.0%[c]	100%	40%

[a] Electricity export in each year minus electricity export in 2005
[b] Linear interpolation between 0 kWh/MT cane with 0% straw in 2005 to 89.3 kWh/MT cane with 40% straw in 2020
[c] Macedo et al. (2008)
[d] From Table 1
[e] Share of straw for electricity generation divided by share of unburned cane harvesting area

Mechanical harvesting contributes significantly to the energy consumption of farming sugarcane. The July 2012 release of GREET1 (GREET1_2012 rev.1) increased the energy consumption in sugarcane farming from 41,952 Btu/tonne cane to 95,000 Btu/tonne cane (Dunn et al., 2011). Energy consumption per tonne during sugarcane harvesting is assumed to be constant between 2010 and 2020 despite the increased mechanical harvesting share.

3. Sugarcane Ethanol Production and Application of Residues

The adjustments to GREET1 include the downward revision of the sugarcane ethanol yield from 25 to 21.4 gal/tonne cane (Seabra et al. 2011). Additionally, the impact of application of sugarcane ethanol production residues (such as vinasse and filtercake) to soil is now considered.

With some variations by local climate, sugarcane varieties, and cultural practices, the typical sugarcane crop cycle in Brazil is six years. The first year is a harvest year, followed by four years of ratooning and then one field reforming year. Vinasse is applied during the ratooning periods while filtercake is applied during the reforming period. Table 3 summarizes vinasse yields from Macedo et al. (2008), Seabra et al. (2011) and Lisboa et al. (2011)showing a range of 364 – 884 L/tonne cane. The December 2012 release of GREET1 (GREET1_2012 rev.2) adopts the availability in Seabra et al. (2011) (570 L/tonne cane) and assumes all available vinasse is applied to soil. Macedo et al. (2008) assumed that filtercake is applied at 5 dry tonne/ha on 30% of the reforming areas. With 82.4 – 95 tonne cane/ha of sugarcane yields, the filtercake application was estimated to be 2.6 – 3 dry kg/tonne cane. Filtercake availability was assumed to be 6 – 8 dry kg/tonne cane (Macedo et al. 2008) or 31 wet kg/tonne cane (Seabra et al. 2011). GREET1 now adopts 2.87 dry kg/tonne cane (the 2005/2006 values in Macedo et al. (2008)) for filtercake application. The moisture content of filtercake is estimated to be 65%, an average of the moisture contents in Moberly and Meyer (1978) and Ensinas et al. (2007).

Table 3 Availability and application of vinasse from sugarcane ethanol plants

	L/tonne cane
Macedo et al. (2008): Year 2002	364
Macedo et al. (2008) : Year 2005/2006	825
Macedo et al. (2008) : Year 2008	884

Seabra et al. (2011): Year 2008	570
Lisboa et al. (2011)	508

When vinasse and filtercake are applied to soil, N_2O emissions are generated from the N in the vinasse and filtercake. The N content of vinasse was reported at 0.28 g/m^3 by Macedo (2005) and 0.36 g/m^3 by Macedo et al. (2008). The recent value from Macedo et al. (2008) is adopted in this GREET release. For filtercake, 1.25% N on a dry weight basis is used (Macedo, 2007). Moreover, the N_2O emission factor is calculated to be 1.22% N in N_2O/N (Wang et al., 2012).

Filtercake transport energy and emissions burdens are included assuming that it is trucked for 12 miles and has a moisture content of 65%. On the other hand, energy consumed during vinasse transport is not included because it is typically transported through closed and open channels and sprinklers. CH_4 emissions from anaerobic digestion of vinasse could be a potentially important GHG emission source during vinasse transport. The reported CH_4 emissions show a large variation: 0 – 10 mg CH_4-C/m^{2}h in Lisboa et al. (2011) and 386 – 1,431 mg CH_4-C/m^{2}h in de Oliveira Bordonal et al. (2012). With the values in de Oliveira Bordonal et al. (2012), the impact of CH_4 emissions from anaerobic digestion of vinasse on the WTW GHG emissions of sugarcane ethanol would be 1.2 g/MJ. As more vinasse would be transported via closed channels and pipelines, the impact is expected to be reduced significantly in the future. Because of large uncertainty and possible significant reductions in the future, CH_4 emissions during vinasse transport are not included in GREET.

4. Supplemental Fertilizer Inputs

The July 2012 GREET1 release (GREET1_2012 rev.1) adjusted sugarcane farming fertilizer inputs based on Macedo et al. (2008) and Seabra et al. (2011). The fertilizer inputs took into account the credits for displaced conventional fertilizers by the sugarcane straw left in soil and the ethanol production residues in 2010. Since more straw will be recovered in the future, more conventional fertilizers will be required to maintain the soil nutrients. The incremental increases in fertilizer input from the 2010 level are calculated considering the decrease in straw left in fields and its N, P and K content (Table 4). N_2O emissions from N in straw are also included using the N_2O emission factor estimated in Wang et al. (2012). Filtercake and vinasse application may displace conventional fertilizer, which would reduce life-cycle GHG emissions and energy consumption of sugarcane. These impacts, however, are not included because application rates do not deviate from the current level.

Table 4 Nutrient contents in sugarcane straw

	N content	P content	K content
Macedo (2007)	0.37%	0.03%	1.25%
Seabra et al. (2011)	0.60%		
Lisboa (2011)	0.50%		
Gava et al. (2005)	0.64%		
Adopted in GREET	0.37%	0.03%	1.25%

5. Sugarcane Ethanol Transport

Sugarcane ethanol produced in Brazil is transported to major ports (such as Santos and São Paulo) and shipped to the U.S. Ethanol transport over land in Brazil is expected to be by trucks. The distance is now reduced from 500 miles to 430 miles in order to reflect the actual distance from North São Paulo to major ports in Brazil. The ocean transport distance is unchanged at 7,416 miles. The ocean tankers transporting sugarcane ethanol are typically smaller than those that carry crude oil. Therefore, the December 2012 GREET1 release (GREET1_2012 rev.2) creates a small ocean tanker class whose payload and speed are 22,000 ton and 13 mph, respectively.

6. Reference

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