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February 17, 2015

California Air Resources Board
Katrina Sideco
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Reference: **Comments on the Treatment of Nitrogen Fixation in Soybeans**

Dear Ms. Sideco,

Life Cycle Associates would like to take this opportunity to provide comments and insight to the recently released California GREET2.0 model. The comments herein address the analysis and treatment of N_2O emissions from soybean farming and time impacts on biofuel pathways. These comments are a continuation of comments submitted on 10/28/2014 addressing the same issue, which has not been addressed in the new release. CA_GREET2.0 estimates the releases of N_2O due to fertilizer application, crop residue, volatilization, and the secondary effects from leaching as per the IPCC methods. GREET does not include emissions from nitrogen fixation in legumes. The emissions from the nitrogen fixed in the plants are a major contributor to lifecycle greenhouse gas emissions from soybeans, which affects soy bio- and renewable diesel pathways as well as co-product credits for other pathways. Table 1 shows the impacts of addressing N_2O fixation on the CA_GREET2.0 soy biodiesel and corn ethanol fuel pathways. The effect of the N fixation on the corn ethanol pathway is due to the higher DGS co-product credit obtained for displacing the higher emissions soybean meal animal feed.

Table 1. N_2O fixation Impact on corn ethanol and soy biodiesel fuel pathways.

	GHG Emissions (g CO_2e/MJ_{Fuel})	
Model	**Soy Biodiesel**	**Corn Ethanol**
CA_GREET2.0	1.6	18.3
CA_GREET2.0, N Fixation	6.8	15.3
Difference in Pathway	**5.2**	**-3.0**

GHG Impacts of Nitrogen Fixation in Legumes

The emissions from soybean production have been examined in many fuel LCA models and the latest research from the JRC's GNOC model as well as other studies shows that the emissions from nitrogen fixation are significant. The effect is well described by Venkat, 2010:

> "IPCC (2006) does not include biological nitrogen fixation as a direct source of N_2O, instead relying solely on the nitrogen inputs from crop residues (above and below ground) to account for all legume N_2O emissions. The problem with this is that the IPCC crop residue model does not seem to capture the magnitude of N_2O emissions in the late-growth stages of soybeans (this is the one crop that I have looked at in detail; others may have a similar problem). There is in fact almost an order of magnitude difference between the worst-case (high) N_2O emissions from crop residue and the conservative (low) N_2O emissions in the late-growth stages (crop residue emissions are smaller by a factor of 5 to 10)."

These comments address the N_2O release from soybean farming in GREET and CA_GREET2.0 and compare the results to the EPA RIA analysis, the EU GNOC (Global Nitrous Oxide Calculator) and the 2013 JRC WTT report. Results from these studies suggest that the GREET inputs underestimate the N_2O emissions from soybean production, which affects soy biodiesel, renewable diesel, and corn ethanol pathways with soy displacing corn. Figure 1 shows the N_2O

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contribution to the total GHG emissions of the finished fuel produced, based on data from GREET and the various leading studies addressed in these comments.

ARB should evaluate these studies and re-examine the GREET methodology and values to ensure that the treatment of corn and soy is commensurate to the N_2O emissions generated.

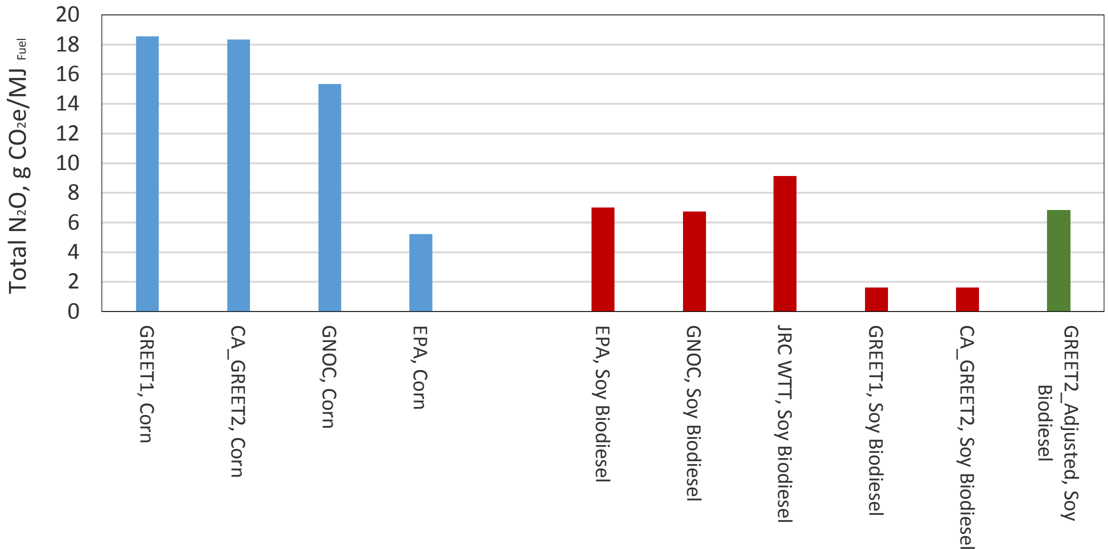

Figure 1. N_2O contribution to GHG emissions from corn and soy crops.
[a] Emissions are calculated from GREET data and data in the EU and EPA studies, crop yields are based on 2014 NASS data for corn and soy.

EPA RIA N_2O Emissions Analysis

The EPA evaluated the nitrous oxide emissions for soy and corn biomass as part of the RIA analysis (EPA, 2013). Figure 2 shows the N_2O emissions from bioenergy crops in the U.S as presented in the EPA RIA. The N_2O emissions attributed to the crop residue and leaching from soy and corn bioenergy crops account for approximately 40% and 25% of the total N_2O emissions.

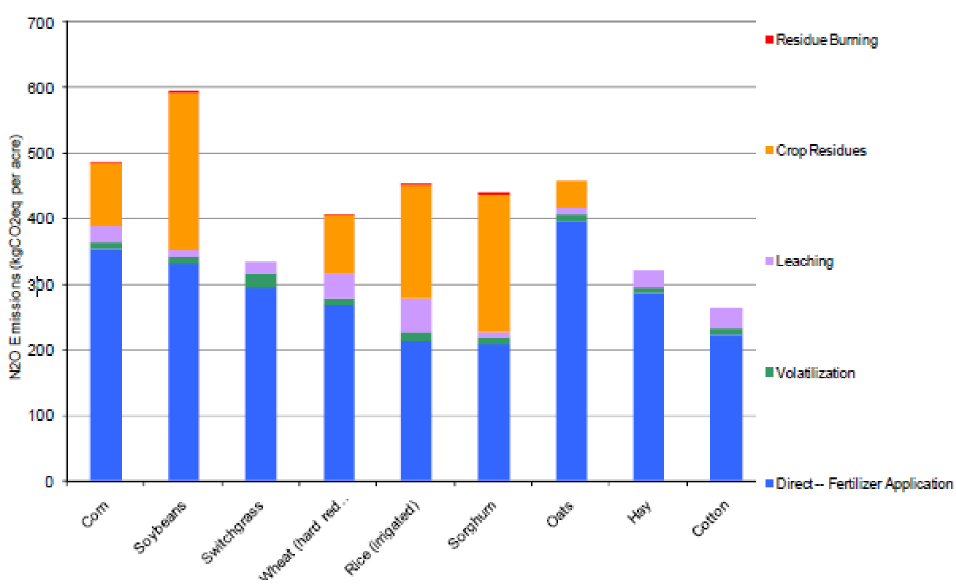

Figure 2. EPA RIA N_2O emissions form bioenergy crops

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Table 2 shows the N_2O emissions from the biomass fixation and leaching and also the contribution of these emissions to the total GHG emissions of the finished fuel produced, based on the EPA RIA. NASS average crop yields for 2014 is assumed for calculation of the total N_2O emissions (kg/ha).

Table 2. EPA RIA Nitrous Oxide Emissions from Soybean and Corn Farming

EPA RIA Result	Corn	Soybean
Fertilizer and Leaching	2.98	2.82
Crop Residue	0.83	19.9
Total N_2O, g/bu	3.81	22.7
Total N_2O, kg/ha*	1.8	2.2
g CO_2e/MJ_{Fuel}	**5.2**	**7.0**

*NASS 2014 Average crop yield assumed for conversion to kg/ha.

JRC GNOC N_2O Emissions Analysis

The European JRC GNOC (Global Nitrous Oxide Calculator) (Köble, 2014) calculates N_2O emissions based on the 2006 IPCC guidelines (Eggleston, 2006) combining TIER1 and TIER2. The IPCC guidelines distinguishes different pathways (direct, indirect) and different nitrogen sources (e.g. mineral fertilizer, manure, crop residues, and drained organic soils). For the indirect pathways (leaching/runoff and volatilization) the GNOC follows the IPCC TIER1 approach for all nitrogen sources. The same holds for direct emissions from crop residues and drained organic soils.

Table 3 shows the GNOC and the JRC WTT study (CONCAWE, 2013) N_2O emissions from soy and corn farming and also the contribution of these emissions to the total GHG emissions of the finished fuel produced.

Table 3. JRC GNOC Nitrous Oxide Emissions from Soybean and Corn Farming

N_2O result	GNOC, Corn	GNOC, Soybean	JRC WTT
Region	Iowa	Iowa	EU
Crop	Corn	Soybean	Soybean
Crop Yield, kg/ha	23,827	5,291	--
Chemical N, kg/ha	198	3.05	--
Manure N, kg N/ha	0	0	--
Total N_2O, g/bu	9.16	21.57	29.53
Total N_2O, kg/ha	4.36	2.13	2.92
g CO_2e/MJ_{Fuel}	12.6	6.7	9.1

GREET N_2O Emissions Analysis

Table 4 shows the GREET N_2O emissions from soybean and corn farming and the contribution of these emissions to the total GHG emissions of the finished fuel produced. Table 4 also shows the GREET2 soybean results if a constant for N fixation in the biomass consistent with the GNOC results was applied. A constant for the corn analysis can also be applied (not shown here).

GREET does not include biological nitrogen fixation as a direct source of N_2O, instead relying on the nitrogen inputs from crop residues to account for total N_2O emissions. As previously stated by Venkat, 2010, this analysis does not accurately capture the magnitude of N_2O emissions in the late-growth stages of soybeans. The omission of nitrogen fixation leads to a misrepresentation of

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the total GHG emissions from soybeans and affects the soy biofuel pathways and other pathways where soybean meal is a substitute co-product.

Table 4. N_2O emissions from soybean and corn pathways.

Case	*GREET1_ Corn	CA_GREET2_ Corn	GNOC, Corn	*GREET1_ Soy	CA_GREET2_ Soy	GNOC, Soy	+Soy, matched GNOC
Chemical N, g/bu	423.3	415.3		49.9	49.9		49.9
Crop Density, lb/bu	56	56		60	60		60
Crop Yield							
bu/acre	158	191		40	40		40
kg/ha	19,506	23,580	19,506	5,291	5,291	5,291	5,291
N Fertilizer, g/acre	165,197	195,926		4,930	4,930		4,930
N in Biomass, g	141.6	142.6		200.7	201.7		200.7
Chemical N, kg/ha	165.2	195.9	165	4.93	4.93	4.93	4.93
Crop Residue N kg/ha	55.26	67.27		19.83	19.93		19.8
N_2O Chemical	1.525%	1.525%		1.325%	1.325%		1.325%
N_2O Crop Residue	1.525%	1.525%		1.325%	1.325%		1.325%
N_2O from fixation, g/bu							17
GREET Result N_2O kg/ha							
Chemical Fertilizer	3.96	4.70		0.10	0.10		0.10
Crop Residue	1.32	1.61		0.41	0.41		0.41
Total N_2O, g/bu	13.5	13.4	11.2	5.2	5.2	21.8	22.1
Total N_2O kg/ha	5.28	6.31	4.36	0.52	0.52	2.16	0.52
g $CO2_e/MJ_{Fuel}$	18.6	18.3	15.3	1.6	1.6	6.7	6.8

*GREET1 cases are determined using GREET1_2014.
+ Soy matched to GNOC include N_2O from legume fixation.

Figure 3 shows a graphical comparison of the GREET N_2O emissions (g/ha) versus the leading studies identified here. The GREET Soybean N_2O emissions (kg/ha) are ~ 5 times lower than the other leading studies.

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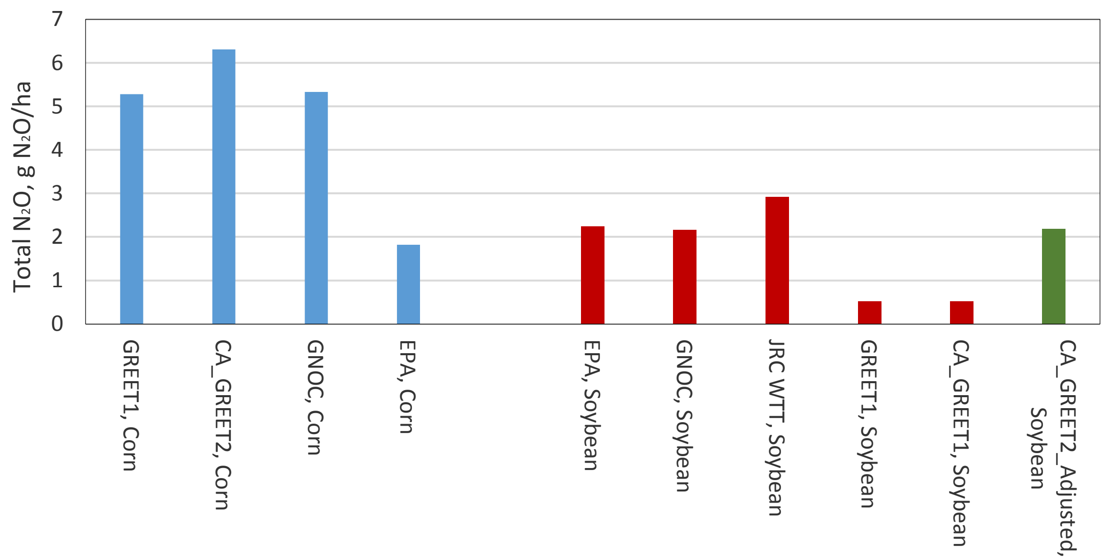

Figure 3. Total N_2O emissions from corn and soybean production.

Figure 4 shows the CA_GREET2 calculation array for soybean farming. An additional term to account for the N_2O from biomass fixation has been added (highlighted in yellow). The WTT results array for the CA_GREET2 adjusted case is shown in Figure 5.

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	Soybeans							
	Soybean Farming	Soybean Farming Fertilizer Use (grams/bushel)				Soybean Farming Herbicide and Pesticide Use (grams/bushel)		Soybean Transportation
Energy consumed: Btu/mmBtu of fuel throughput, except as noted	**Per bushel of soybeans**							
Total energy	20,959	3,024	5,115	3,028	0	5,696	200	5,914
Fossil fuels	20,688	2,987	4,917	2,791	0	5,422	190	5,885
Coal	1,020	138	740	887	0	1,023	37	112
Natural gas	4,277	2,560	3,009	929	0	1,708	61	580
Petroleum	15,392	289	1,168	975	0	2,690	92	5,193
Total emissions: grams/mmBtu of fuel throughput, except as noted	**Per bushel of soybeans**							
VOC	2.013	0.315	0.328	0.042	0.000	0.053	0.002	0.116
CO	33.393	0.376	0.602	0.193	0.000	0.319	0.015	0.444
NOx	14.086	0.433	1.560	0.732	0.000	1.070	0.045	1.071
PM10	0.911	0.075	0.322	0.068	0.000	0.118	0.003	0.029
PM2.5	0.867	0.061	0.253	0.050	0.000	0.074	0.003	0.024
SOx	1.029	1.021	16.790	0.503	0.000	1.520	0.034	0.172
CH4	2.749	0.520	0.772	0.392	0.000	0.704	0.025	0.613
N2O	0.027	0.201	0.008	0.004	0.000	0.008	0.000	0.008
CO2	1,545	159	349	224	0	430	15	465
VOC from bulk terminal	0.000	CO2e from LUC		0.695	NO from nitrogen fertilizer			
VOC from ref. Station		45.386	CO_2 from urea use	5.218	N2O from nitrogen fertilizer			
				17.000	N2O from fixation			

Figure 4. CA_GREET2 soybean farming calculation array.

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	Soy Oil-based Biodiesel	
	Feedstock	**Fuel**
Loss factor		1.000
Unit	per mmBtu	per mmBtu
Total energy	51,578	588,260
Fossi lfuels	50,337	262,702
Coal	4,644	63,780
Natural gas	15,407	170,644
Petroleum	30,286	28,278
VOC	3.369	23.321
CO	41.489	14.717
NOx	23.117	36.254
PM10	1.791	3.390
PM2.5	1.565	2.703
SOx	24.733	21.631
CH4	6.780	39.531
N2O	26.383	0.333
CO2	3,794	18,696.679
CO2 (w/ C in VOC & CO)	3,870	18,789
GHGs	11,901.6	19,877
g CO2e/MJ	**11.28**	**18.84**

Figure 5. CA_GREET2 soybean biodiesel WTT results array.

We hope that these comments have illustrated that the N_2O emissions in GREET are in need of thorough evaluation. Thank you for taking into account these comments. I look forward to discussing these comments with you in more detail.

Best Regards,

Stefan Unnasch
Managing Director
Life Cycle Associates, LLC

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