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September 22, 2014

California Air Resources Board
Katrina Sideco
(916) 323-1082
ksideco@arb.ca.gov

Reference: **Comments on a Simplified Equation for the CI of Biofuel Pathways and Fugitive Emissions.**

Dear Ms. Sideco,

Life Cycle Associates would like to take this opportunity to provide comments and insight to the development of simplified pathways under the new California GREET model, whereby a reduced form equation could provide another alternative to the GREET model or ARB's proposed tool for calculating the Carbon Intensity (CI) for many biofuel pathways. The comments herein also address the analysis of corn ethanol and illustrate the effect of DGS displacement ratios, enteric fermentation, and fugitive VOC emissions in GREET1. These comments are intended to illustrate a simplified approach and are adaptable to any version of the GREET model and any fuel pathway.

ARB has indicated that they are working on a simplified method for determining the CI of corn ethanol and other biofuels based on the new CA_GREET model, which would be appropriately named CA_GREET1_2013. Comments from the August 22, 2014 workshop suggested that a simple spreadsheet was under development. For select pathways such as dry mill corn ethanol, ARB could provide a simple reduced form equation for most fuel pathways thereby eliminating the need to deal with the GREET model other than for transportation. This approach would lower the need for ARB staff time and turn-around times for fuel pathways.

Reduced form Equation

The reduced form linear equation for calculating the CI of corn ethanol presented here is based on the four key process inputs (ethanol yield, DGS yield, natural gas and electricity use) that are the current inputs to the GREET model. ARB could also develop a separate equation to calculate the ethanol transport emissions (not discussed here) or calculate these emissions using GREET.

Using the following equation calculated the CI for corn ethanol based on GREET1_2013:

$$E_{EtOH,\ WTT} = (A_{feedstock} / \psi_{EtoH}) - (A_{Co\text{-}prod} / \psi_{DGS} + E_f) + (E_{NG} \times Ai_{NG}) + (E_{Electricity} \times Ai_{Electricity}) + C_{E+Y} + E_{vent} \times 0 + T\&D_{EtOH}$$

$$= (108.3 / 2.81) - (72.5 / 5.63 + 2.14) + (24{,}343 \times 9 \times 10^{-4}) + (2{,}533 \times 1.7 \times 10^{-3}) + 0.63 \times 0 + 1.26$$

$$= 53.6 \text{ g } CO_2e/MJ$$

A detailed explanation of the GREET calculations and the reduced form linear equation is provided in the appendix for reference. The reduced from equation above is derived from the disaggregated emissions provided in the appendix.

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Co-Product Credits, Enteric Fermentation, and Updated Plant Parameters

The calculations herein incorporate the GREET1 parameters for DGS displacement and enteric fermentation. This analysis for corn ethanol is consistent with ARB's expert working group recommendations on co-products. ARB has used a 1:1 displacement ratio of DGS for corn. This displacement ratio and integration with GTAP should continue to be examined. The reduced form CI for corn ethanol could use any displacement ratio that ARB approves including facility specific parameters.

The GREET1_2013 default DGS credit is based on displacement ratios of corn, soy and urea. CA_GREET1.8b uses a 1:1 displacement ratio of DGS to corn. However, due to its high protein content and ease of digestibility, DGS as an animal feed displaces some soy on the feedlot. ARB should examine the co-product options evaluated in the co-products working group and adopt either the methodology or co-product displacement ratios used in GREET1 to more accurately reflect the conditions in practice. The reduced form equation presented here includes co-product credits based on the GREET default DGS substitution ratios (see appendix for details of calculation).

ARB should also examine the co-product credit for avoided enteric fermentation. The DGS contains a higher N content than other feed. The overall protein content consumed by cattle is arguably the same from DGS as with other feeds, but the significant factor in enteric fermentation is the time required to gain weight. The DGS higher protein content results in shorter time on feedlot, and therefore lower enteric fermentation emissions from ruminant digestion.

The GREET1 ethanol plant emissions now include the use of fermentation enzymes and yeast in the ethanol production process. These emissions were not included in the original CA_GREET.

The combined effect of using the GREET1 DGS displacement ratios, enteric fermentation and the updated plant emissions is a reduction in the $EtOH_{WTT}$ emissions by ~ – 3.4 CO_2e/MJ. The approximate individual contribution of each follows:

- DGS credit, GREET displacement ratios: – 2 g CO_2e/MJ
- Enteric fermentation credit: – 2 g CO_2e/MJ
- Fermentation enzymes and yeast: + 0.6 g CO_2e/MJ

Fugitive Ethanol Emissions

The GREET model counts fugitive VOC emissions from T&D towards total VOC emissions. These VOC emissions are then treated as fully oxidized CO_2 emissions in the GREET model. This treatment is an error since the VOC emissions from ethanol are biogenic. The other ethanol emissions in GREET are treated as carbon neutral. The GREET model subtracts vehicle combustion emissions from the Results page. Fermentation CO_2 emissions are also not explicitly shown and thus not counted towards WTT emissions. VOC emissions appropriately contribute to the loss factor for ethanol production and the corn phase but these emissions should not contribute to fully oxidized CO_2. The impact of not counted fugitive VOC is -0.09 g CO_2e/MJ. This error is profoundly significant because it is a structural calculation issue that relates to the carbon neutral approach for biofuels. Inconsistency in the treatment of biogenic carbon would spread confusion to thousands of followers of the LCFS and therefore should be addressed promptly for all biofuel pathways. Even though the impact is small, these emissions should not count towards WTT GHG emissions.

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Summary

The comments outlined here address important aspects of the corn ethanol pathway and the simplified reduced form equation provides many advantages for streamlining the LCFS pathway application process. The savings in staff time alone could allow staff to develop additional fuel pathways and provide a rapid turn-around of pathway applications. Thank you for taking into account these comments.

Please review these comments and the attached appendix of calculations and do not hesitate to contact us if you have any queries. I look forward to discussing these comments with you in more detail.

Best Regards,

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Managing Director
Life Cycle Associates, LLC

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Appendix

GREET Calculation Methodology

This section of the comments deals with the GREET1 calculation steps for the calculation of the $EtOH_{WTT}$ lifecycle GHG emission. The calculations have been updated to reflect the new GREET inputs to the pathway. The corn ethanol WTT lifecycle emissions are calculated in GREET based on the inputs for ethanol production ψ_{EtoH}, ψ_{DGS}, E_{NG} and $E_{Electricity}$, where;

ψ_{EtoH}	= Ethanol Yield
ψ_{DGS}	= DGS Yield
E_{NG}	= Natural Gas (NG) Input
$E_{Electricity}$	= Electricity Input

The GREET calculation of the corn ethanol WTT life cycle emissions are broken into calculation phases, the corn feedstock phase and the ethanol fuel phase. The feed plus the fuel phase comprises the WTT emissions. The feed phase is composed of farming energy including fertilizer and field emissions, corn transport and distribution. The distillers' grain solids (DGS) are also included here. The fuel phase consists of producing fuel from the feedstock, finished fuel transportation and distribution, and vehicle use.

Corn Feedstock Phase

WTT emissions for the Feedstock Phase involve agricultural and corn transport emissions minus co-product credits. In GREET these are shown per bu and then converted to a per mmBtu basis via:

$$E_{Feed} = ((E_{Farm} + E_{Fert}/_{Chem} + E_{T\&D})/\psi gal/bu + E_{CP}) / LHV_{EtOH} \times 10^6$$

where,

E	= data array for life cycle energy and emissions.
E_{Feed}	= farming energy, chemical inputs, primary transportation and co-product credits
E_{Farm}	= farming energy
$E_{Fert/Chem}$	= fertilizer and chemical inputs
$E_{T\&D}$	= transportation and distribution
E_{CP}	= co-product credits
ψ	= corn to ethanol yield in anhydrous gallons per bushel

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LHV_{EtOH} = Lower heating value for ethanol

DGS Co-product Credit

The DGS credit is based on the DGS displacing an alternative product, the displacement ratios for the LCFS and GREET1_2013 shown in Table 1.

Table 1. Co-product Displacement Ratios for Corn Ethanol Production

Products Displaced by DDGS	Displacement Ratio, lb/lb DDGS	
	LCFS_2009	GREET1_2013
$\Omega_{\text{Feed corn}}$	1.00	0.78
$\Omega_{\text{Soybean meal}}$	0.00	0.31
$\Omega_{\text{N-urea}}$	0.00	0.02

The co-product displacement credit for DGS based on the substitution ratios (Ω) for corn soybean meal (SBM) and Urea can be calculate as follows:

$$E_{CP} = \Omega_{Corn} \times E_{Corn} \times M_{DGS}/M_{Corn} + \Omega_{SBM}\, E_{SBM} \times M_{DGS}/M_{Corn} + \Omega_{Urea}\, E_{Urea} \times M_{DGS}/M_{Corn} + E_f$$

Where,

Ω = DGS Substation ratio

E = Data array for life cycle energy and emissions.

M_{DGS} = Mass of DGS, bone dry basis (lb/bu).

M_{Corn} = Density of corn, bone dry basis (48 lb/bu).

E_f = Enteric Fermentation Credit, GREET default.

Ethanol Fuel Phase

The Ethanol Fuel Phase, includes natural gas combustion, electric power and fugitive emissions from the plant. Minor chemicals are not included because the emissions are below the cutoff criteria selected by the GREET developers. GREET1_2013 also includes plant fermentation enzymes and yeast. Transport and distribution of the fuel is also included in the fuel phase. To estimate WTT emissions for the Fuel Phase, the following equation is employed:

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$$E_{Fuel} = (E_{Plant} \times LF_{D,S}) / LHV_{EtOH} + E_{T\&D}$$

where,

E_{Plant} = Ethanol plant emissions, including natural gas combustion, electric power and fugitive emissions from the plant

$E_{T\&D}$ = transportation and distribution

$LF_{D,S}$ = loss factor for distribution and sale

The loss factor (LF) represents the fuel lost in the fuel life cycle due to evaporation, spillage, or self use and requires additional upstream activity to make up for these losses. For example, evaporation and spillage (r) of 12 g ethanol out of 8 gallons of fuel volume (v) leads to an LF of 0.0005 as per the following calculation where 2,988g/gal is the density of ethanol:

$$LF_{D,S} = 1 + v / (r \times v)$$

$$12 \text{ g} / (8 \text{ gal} \times 2{,}988 \text{ g/gal}) = 1.0005$$

To account for the loss factors, the feedstock and ethanol plant need to increase output by 1.0005. These values add some difficulty in verifying calculations from different feedstocks. The loss factors for ethanol are the same as those for gasoline:

6.66 g/mmBtu from bulk terminal

13.0 g/mmBtu from fueling station

More accurate loss factors could be calculated based on actual fuel logistics. E_{Plant} includes the emissions from natural gas combustion and the WTT for electric power.

$$E_{Plant} = S_{NG} \times E_{NG} + S_e \times E_e + C_{E+Y} + E_{vent}$$

Where,

S_{NG} = Specific energy of natural gas, (Btu/gal)

E_{NG} = GREET data for upstream fuel cycle for natural gas

S_e = Specific energy of electric power (Btu_e/gal)

E_e = GREET data for upstream fuel cycle for power

C_{E+Y} = Constant, Emissions for Fermentation Enzymes plus Yeast

E_{vent} = Fugitive emissions, GREET default

WTT Emissions

The total WTT emissions for the corn ethanol process are given by the following equation:

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$$E_{EtOH,\ WTT} = E_{Corn} \times LF_{D,S} + E_{Fuel}$$

where,

E_{Corn} = farming energy, chemical inputs, primary transportation and co-product credits

E_{Fuel} = production of ethanol

$E_{T\&D}$ = transportation and distribution

Reduced form linear equation

For a dry mill ethanol plant, the $EtOH_{WTT}$ Lifecycle GHG emissions can also be calculated using a simplified reduced form equation based on four process inputs (ethanol and DGS yield, natural gas and electricity usage). Enteric fermentation credit, the fermentation enzymes and yeast and the plant fugitives are constant terms in GREET and are not affected by ethanol plant performance. The linear equation for calculation of the $EtOH_{WTT}$ pathway lifecycle GHG emissions is:

$$E_{EtOH,\ WTT} = (A_{feedstock} / \psi_{EtoH}) - (\psi_{DGS} \times ((\Omega_{corn} \times A_{Corn}) + (\Omega_{SBM} \times A_{SBM}) + (\Omega_{Urea} \times A_{Urea})) + E_f) + (E_{NG} \times A_{NG} \times LHV_{ETOH} / 10^{-6}) + (E_{Electricity} \times A_{Electricity} \times LHV_{ETOH} / 10^{-6}) + C_{E+Y} \times 0 + E_{vent} + T\&D_{EtOH}$$

Where;

A	= GREET result
ψ_{EtoH}	= Ethanol Yield
ψ_{DGS}	= DGS Yield
E_{NG}	= NG Input
$E_{Electricity}$	= Electricity Input
E_f	= Enteric Fermentation credit
C_{E+Y}	= Constant, Emissions for Fermentation Enzymes plus Yeast
E_{vent}	= Non Combustion Emissions
$T\&D_{EtOH}$	= Ethanol Transport and Distribution

This formula is further reduced to a simplified form such that:

$$E_{EtOH,\ WTT} = (A_{feedstock} / \psi_{EtoH}) - (\psi_{DGS} \times A_{Co\text{-}prod}) + (E_{NG} \times A_{NG}) + (E_{Electricity} \times A_{Electricity}) + C_{E+Y} \times 0 + T\&D_{EtOH}$$

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The GREET1_2013 default input assumptions for corn ethanol are shown in Table 2.

Table 2. GREET1_2013 Process Inputs to the Corn Ethanol Pathway

Input Assumptions	GREET Inputs	Units
Natural Gas	24,323	Btu/gal, LHV
Electricity	2,533	Btu/gal
DGS	5.63	lb DGS/gal
Ethanol Yield	2.8	gal/bu corn

Using the simplified reduced form linear formula equation and the GREET1_2013 corn ethanol process inputs, the carbon intensity calculation is as follows:

$$E_{EtOH,\ WTT} = (A_{feedstock} / \psi_{EtoH}) - (A_{Co\text{-}prod} / \psi_{DGS} + E_f) + (E_{NG} \times Ai_{NG}) + (E_{Electricity} \times Ai_{Electricity}) + C_{E+Y} + E_{vent} \times 0 + T\&D_{EtOH}$$

$$= (108.3 / 2.81) - (72.5 / 5.63 + 2.14) + (24{,}343 \times 9 \times 10^{-4}) + (2{,}533 \times 1.7 \times 10^{-3}) + 0.63 \times 0 + 1.26$$

$$= 53.6 \text{ g } CO_2e/MJ$$

The GREET1 calculations were disaggregated into a stand-alone calculator which displays the discreet emissions per farming and production step. This disaggregation of GREET calculations demonstrate the emissions for each step in the fuel pathway. Table 3 shows the disaggregated result for Corn Ethanol with GREET1_2013 input data.

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Table 3. Disaggregated result for Corn Ethanol with GREET1_2013 input data.

Pathway Group	**Farming and Transport**												
Emission Source	**Feedstock Farming**	**CO_2 emissions from land use change**	**Nitrogen Fertilizer**	**Field Emissions**	**P_2O_5**	**K_2O**	**$CaCO_3$**	**Field CO_2 from $CaCO_3$ and Urea**	**Herbicide**	**Insecticide**	**Feedstock Transport (Btu/bu, g/bu)**	**Corn Feedstock (Btu/bu, g/bu)**	**Corn Feedstock (g/MMBtu)**
Loss Factor	**Energy, Emissions/bu**												
Total energy **(Btu/unit)**	12,068		25,078		3,630	1,494	198		1,256	126	5,515	49,365	230,973
Fossil fuels	11,877		24,803		3,502	1,386	197		1,200	120	5,490	48,575	227,280
Coal	812		1,164		543	456	9		234	24	111	3,352	15,685
Natural gas	3,726		21,251		2,132	449	19		371	38	530	28,515	133,421
Petroleum	7,338		2,388		828	481	170		595	58	4,848	16,708	78,173
VOC **Emissions (g/unit)**	0.651		2.616		0.231	0.024	0.007		0.013	0.002	0.180	3.723	17.4
CO	3.121		2.902		0.385	0.077	0.027		0.047	0.006	0.636	7.200	33.7
NOx	6.174		3.862	9.428	1.140	0.343	0.082		0.168	0.018	2.089	23.303	109.0
PM10	0.427		0.641		0.232	0.043	0.008		0.041	0.004	0.121	1.518	7.1
PM2.5	0.372		0.520		0.180	0.033	0.005		0.030	0.003	0.099	1.242	5.8
SOx	0.427		8.464		11.996	0.197	0.006		0.147	0.009	0.131	21.377	100.0
CH_4	1.981		4.900		0.598	0.197	0.020		0.160	0.016	0.545	8.417	39.4
N_2O	0.023		1.670	13.346	0.005	0.002	0.000		0.001	0.000	0.007	15.055	70.4
CO_2	892.447	0.000	1312.684		248.493	111.488	15.667	884.000	95.236	9.343	432.978	4,002	18,727
CO_2 including VOC & CO	899.4	0.0	1,325.4	0.0	249.8	111.7	15.7	884.0	95.3	9.4	434.5	4,025.3	18,833.9
Total GHG (g CO_2e/unit)	**956**	**0**	**1,945**	**3,977**	**266**	**117**	**16**	**884**	**100**	**10**	**450**	**8,722**	**40,810**
(g CO2/mmBtu)	**4,471**	**0**	**9,103**	**18,609**	**1,246**	**548**	**76**	**4,136**	**467**	**46**	**2,107**	**40,810**	
(g CO_2e/MJ)	**4.2**	**0.0**	**8.6**	**17.6**	**1.2**	**0.5**	**0.1**	**3.9**	**0.4**	**0.0**	**2.0**	**38.7**	**38.7**
Variables	E_{farm}	$E_{landuse}$	$E_{nitrogen}$	$E_{NO, N2O fie}$	E_{P2O5}	E_{K2O}	E_{CaCO3}	$E_{CO2 urea, C}$	E_{herb}	E_{insect}	$E_{T\&D}$	E_{feed}	
Equations		$E_{fert/chem} = \Sigma(E_{landuse}, E_{nitrogen}, E_{NO, N2O field}, E_{P2O5}, E_{K2O}, E_{CaCO3}, E_{CO2 urea, CaCO3}, E_{herb}, E_{insect})$										$\Sigma(E_{farm}, E_{fert/chem}, E_{T\&D})$	
Sum by group	$E_{feed} = E_{farm} + E_{fert/chem} + E_{cp}$												
WTT sum	$E_{EtOH, WTT} = E_{feed} \times LF_{T\&D} + E_{fuel}$												
RT Lookup Region	US												

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Table 3. ctd. Disaggregated result for Corn Ethanol with GREET1_2013 input data.

Pathway Group	**Co-Product Credits**					**Total Feed Phase**	**Ethanol Production**						
Emission Source	**Displaced Corn (Btu/gal, g/gal)**	**Soybean Meal (Btu/gal, g/gal)**	**Displaced Urea (Btu/gal, g/gal)**	**Enteric CO_2 (Btu/gal, g/gal)**	**Total Credits (Btu/MMBtu, g/MMBtu)**		**NG Boiler (Btu/gal, g/gal)**	**Electric Power (Btu/gal, g/gal)**	**Coal Power (Btu/gal, g/gal)**	**Energy Loss (Btu/gal)**	**"Ethanol Production" (g/gal)**	**Fermentation Enzymes (g/gal)**	**Ethanol Production, Non-Combustion (Btu/gal, g/gal)**
Loss Factor													
Total energy **(Btu/unit)**	-3,880	-2,888	-1,749		-111,572	119,401	26,917	6,102	0	63,983	97,002	690	
Fossil fuels	-3,818	-2,808	-1,733		-109,499	117,781	26,902	5,245	0		32,147	607	
Coal	-263	-715	-68		-13,705	1,979	62	3,624	0		3,687	281	
Natural gas	-2,241	-1,261	-1,563		-66,356	67,065	26,736	1,477	0		28,213	310	
Petroleum	-1,313	-832	-101		-29,437	48,736	104	144	0		248	17	
VOC **Emissions (g/unit)**	-0.293	-0.591	-0.176		-13.9	3.542	0.287	0.048	0.000		0.335	0.007	2.239
CO	-0.566	-0.325	-0.190		-14.2	19.531	1.064	0.125	0.000		1.188	0.023	
NOx	-1.832	-0.700	-0.197		-35.8	73.276	2.112	0.594	0.000		2.706	0.064	
PM10	-0.119	-0.101	-0.018		-3.1	3.972	0.089	0.149	0.000		0.237	0.013	0.856
PM2.5	-0.098	-0.068	-0.015		-2.4	3.442	0.087	0.088	0.000		0.175	0.008	0.146
SOx	-1.680	-0.545	-0.059		-29.9	70.101	0.291	1.263	0.000		1.554	0.106	
CH_4	-0.662	-0.455	-0.352		-19.2	20.141	5.746	0.803	0.000		6.548	0.105	
N_2O	-1.183	-0.168	-0.003		-17.7	52.700	0.057	0.007	0.000		0.064	0.002	
CO_2	-314.578	-212.086	-65.145	-2260	-10,013.3	8,713.374	1607.501	462.858	0.000		2070.359	47.946	
CO_2 including VOC & CO	-316.4	-214.4	-66.0	-2,260.0	-10,078.8	8,755.1	1,610.1	463.2	0.0	0.0	2,073.3	48.0	7.0
Total GHG (g CO_2e/unit)	**-8,981**	**-3,616**	**-990**	**-2,260**	**-15,847**	**24,963**	**1,771**	**485**			**2,256**	**51**	**0**
(g CO2/mmBtu)					**-2,812**		23,196	6,359	**2,073**		29,555		0
(g CO_2e/MJ)	**-8.5**	**-3.4**	**-0.9**	**-2.1**	**-15.0**	23.66	**21.9856**	**6.0**			**28.013**	**0.048**	**0.0**
		-12.9									**28.0**		
Variables	E_{DGS}	E_{SBM}			E_{CP}	E_{corn}	E_{NG}	E_{elec}		$E_{ferment}$	E_{prod}		E_{vent}
Equations		$E_{CP} = SUM(E_{DGS}, E_{SBM}, E_{urea})$								$E_{plant} = \Sigma(E_{NG}, E_{elec}, E_{ferment}, E_{prod}, Event)$			
Sum by group													$E_{fuel} = E_{plant}$ +
WTT sum													
RT Lookup Region	US												MW

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Table 3. ctd. Disaggregated result for Corn Ethanol with GREET1_2013 input data.

Pathway Group			**Ethanol T&D**			**Total Fuel Phase**	**WTT Total**
Emission Source	**Ethanol Plant (Btu/gal, g/gal)**	**Ethanol Plant (Btu/MMBtu, g/MMBtu)**	**Ethanol T&D (Btu/mmBtu, g/mmBtu)**	**Distribution Fugitives (g/mmBtu)**	**Ethanol Storage (g/mmBtu)**		**Total WTT (Btu/mmBtu, g/mmBtu)**
Loss Factor			1.0005	1.0000	1.0000		
Total energy **(Btu/unit)**	33,708.687	441,839	15,854			457,693	577,094
Fossil fuels	32,754.506	429,332	15,280			444,612	562,393
Coal	3,967.305	52,002	301			52,302	54,281
Natural gas	28,522.595	373,862	1,387			375,248	442,313
Petroleum	264.605	3,468	13,593			17,062	65,798
VOC **Emissions (g/unit)**	0.342	4.483	1	19.749		24.9	28
CO	1.211	15.872	3			18.4	38
NOx	2.771	36.318	13			49.2	122
PM10	0.250	3.277	0			3.7	8
PM2.5	0.182	2.390	0			2.8	6
SOx	1.660	21.754	1			22.3	92
CH_4	6.653	87.201	2			88.7	109
N_2O	0.065	0.855	0			0.9	54
CO_2	2,118.305	27,766	1,218			28,983.7	37,697
CO_2 including VOC & CO	2,121.3	27,804.7	1,224.1	61.6	0.0	29,090.3	37,845.4
Total GHG (g CO_2e/unit)	**2,307**	**30,240**	**1,270**	**62**		**31,571**	**56,534**
(g CO2/mmBtu)	30,225						
(g CO_2e/MJ)	**28.6**	**28.7**	**1.2**	**0.1**		**29.923**	**53.6**
Variables	$E_{plant} \times LF_D$		$E_{T\&D}$				$E_{EtOH,\ WTT}$
Equations	$\Sigma(E_{NG}, E_{elec}, E_{ferment}, E_{prod},$						
Sum by group			$E_{T\&D}$				
WTT sum							
RT Lookup Region							