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Energy Efficiency, GHG Balance, and Carbon Credits of Corn-Ethanol: BESS Model Analysis

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Biofuel Energy Systems Simulator (BESS) Analysis of Life-Cycle Energy & GHG Emissions of Corn-Ethanol

1) BESS can analyze an *individual* biorefinery & crop production zone

2) BESS model includes 4 components:

- Crop production
- Ethanol biorefinery
- Cattle model for feeding co-product distiller's grains
- Anaerobic digestion unit (optional, closed-loop facility)

3) Three types of life-cycle analysis:

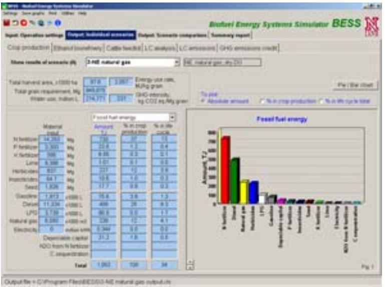
Energy analysis—life-cycle net energy yield & efficiency

Emissions analysis—net carbon dioxide (CO_2) and trace greenhouse gases (CH_4, N_2O), and global warming potentional (GWP/CO2-equivalent)

Resource requirements—crop production area, grain, water, fossil fuels (petroleum, natural gas, and coal)

4) User-friendly model interface for certification of biofuel GHG-intensity.

Fig. 1. BESS Model Interface



BESS Analysis of Corn-Ethanol Biorefinery Types and Regions

-A recent estimate showed that corn-ethanol had a positive energy balance (1.2 out:1 in), and 13% reduction in GHG emissions compared to gasoline (Farrell et al. 2006)

-In contrast, our results using the BESS model, with updated parameters for biorefinery energy use (Energy and Environmental Analysis, Inc 2006) and state-level crop management and yields (see BESS *User's Guide*), gives higher net energy yields and greater GHG mitigation values.

-BESS results are shown below in the tables and map.

Table 1. Input parameters for BESS default simulation scenarios: Output metrics Net Energy Ratio, Net Energy Yield, and GHG emissions intensity & reduction

Default Simulation Scenario:		#1	#2	#3	#4	#5	#6	#7
		USA nat. gas	IA nat. gas	NE nat. gas	NE n.g. wet DG	NE closed -loop	NE coal	NE Progre -ssive
Cropping System Performance (US or state averages)								
Grain Yield	Mg ha^{-1}	9.47	10.7	9.73	9.73	9.73	9.73	13.7
Carbon Sequestration	Mg ha^{-1}	0	0	0	0	0	0	0
Agricultural Input Rates (US or state averages)								
Nitrogen	kg ha^{-1}	150	144	146	146	146	146	177
Phosphorus	kg ha^{-1}	53.3	52.5	33.8	33.8	33.8	33.8	0
Potassium	kg ha^{-1}	61.6	67.4	6.0	6.0	6.0	6.0	0
Lime	kg ha^{-1}	254	334	86	86	86	86	0
Herbicide	kg ha^{-1}	6.19	5.35	6.52	6.52	6.52	6.52	2.21
Insecticide	kg ha^{-1}	0.25	0.06	0.56	0.56	0.56	0.56	0.22
Gasoline	L ha^{-1}	15.7	11.2	19.6	19.6	19.6	19.6	0
Diesel	L ha^{-1}	56.8	43.0	116	116	116	116	40.2
LPG	L ha^{-1}	44.6	67.3	38.3	38.3	38.3	38.3	0
Natural Gas	m^3 ha^{-1}	27.7	0	67.4	67.4	67.4	67.4	0
Electricity	kWh ha^{-1}	98.3	41.5	377	377	377	377	1332
Machinery	MJ ha^{-1}	320	320	320	320	320	320	690
Seed	kg ha^{-1}	20.0	21.3	18.7	18.7	18.7	18.7	29.8
Water	cm	4.9	0.1	22.0	22.0	22.0	22.0	33.3
Biorefinery Energy Inputs (natural gas, coal, or closed-loop)								
Thermal energy, TE	MJ L^{-1}	5.99	5.99	5.99	5.99	3.11	6.15	5.99
TE, drying DG	MJ L^{-1}	2.93	2.93	2.93	-	-	3.96	2.93
Electricity	kWh L^{-1}	0.198	0.198	0.198	0.198	0.291	0.230	0.198
Capital Energy	MJ L^{-1}	0.13	0.13	0.13	0.13	0.26	0.13	0.13
Net Energy Balance and GHG Mitigation Outputs								
Net Energy Ratio	ratio	**1.48**	**1.55**	**1.40**	**1.72**	**2.13**	**1.31**	**1.48**
Net Energy Yield*	GJ ha^{-1}	**30.2**	**37.0**	**27.8**	**41.9**	**50.1**	**23.5**	**44.1**
GHG emissions	%, reduced	**49**	**52**	**47**	**62**	**74**	**21**	**53**
GHG-intensity of ethanol	g CO2eq MJ^{-1}	**45**	**42**	**46**	**33**	**23**	**69**	**42**

For supporting data and references for tables 1-3, please see the BESS Model *User's Guide* at www.bess.unl.edu

Greenhouse Gas Emissions Determined by BESS

-Emissions by component are shown below for the default calculations (Table 2).

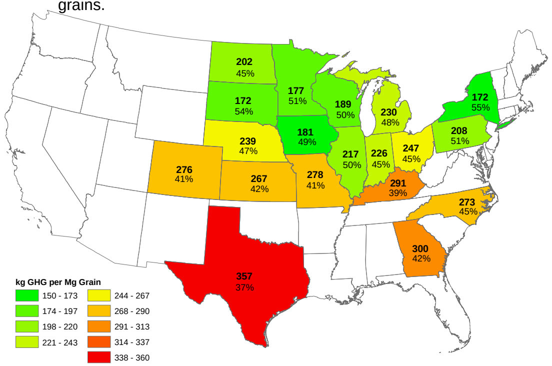
-Co-product distiller's grains substitute corn and urea in cattle diets contributing to significant energy and GHG credits.

-Crop production for ethanol feedstock makes up nearly 50% of life-cycle emissions and thus must be accurately analyzed on a regional basis in corn-ethanol life-cycle studies.

Table 2. Percent of life-cycle GHG emissions by category for BESS Default Scenario #2-#4

Component	GHG emission category	(#2, IA) % of LC	(#3, NE) % of LC	(#4, NE) % of LC
CROP Production				
	Nitrogen fertilizer, N	7.5	7.5	8.6
	Phosphorus fertilizer, P	1.7	1.1	1.2
	Potassium fertilizer, K	1.0	0.1	0.1
	Lime	5.0	1.3	1.5
	Herbicides	2.7	3.2	3.7
	Insecticides	0.0	0.3	0.3
	Seed	0.3	0.3	0.3
	Gasoline	0.6	1.1	1.3
	Diesel	3.1	8.1	9.4
	LPG	2.2	1.2	1.4
	Natural gas	0.0	2.7	3.1
	Electricity	0.5	4.6	5.3
	Depreciable capital	0.5	0.5	0.5
	N Fertilizer emissions (N2O)	13.6	13.5	15.6
	TOTAL	38.7	45.4	52.4
BIOREFINERY	Biorefinery model component			
	Natural Gas Input	30.7	27.4	31.6
	NG Input: drying DG	15.0	13.4	0.0
	Electricity input	10.5	9.4	10.8
	Depreciable capital	0.8	0.7	0.9
	Grain transportation	4.2	3.7	4.3
	TOTAL	61.3	54.6	47.6
CO-PRODUCT CREDIT	Cattle model component			
	Diesel	-0.0	-0.0	-0.6
	Urea production	-9.1	-8.1	-10.0
	Corn production	-14.7	-17.2	-23.8
	Enteric fermentation (CH4)	-2.6	-2.3	-7.0
	TOTAL	-26.4	-27.6	-40.3
	Default co-product credit	*(-45.1)*	*(-40.2)*	*(-46.4)*
GHG reduction relative to gasoline, %	Life-cycle GHG emissions	**52.1**	**47.3**	**61.9**
GHG-intensity, g CO2eq MJ^{-1} of Ethanol	Life-cycle GHG emissions	**42.0**	**46.2**	**33.4**

Figure 2. GHG-intensity of corn production (kg CO2eq/Mg grain), and life-cycle GHG reductions of corn-ethanol compared to gasoline, assuming natural gas biorefinery with drying distillers grains.



	Crop Production Inputs															Corn Production Intensity Metrics					Life-Cycle Metrics			Co-Product Credits	
State	Grain yield 2003-5 Mg ha-1	N 2005 kg N ha-1	P 2005 kgP2O5 ha-1	K 2005 kgK2O ha-1	Lime 2005 kg ha-1	Herb 2005 kg ha-1	Insect 2005 kg ha-1	Seed 2005 kg ha-1	Gas 2001 L ha-1	Diesel 2001 L ha-1	LPG 2001 L ha-1	Nat. gas 2001 m3 ha-1	Elect 2001 kWh ha-1	Capital 2007 MJ ha-1	Electricity Emissions 2004 kg MWh-1	GHG intensity w/ US avg. e-grid kg GHG Mg-1*	Energy use w/ US avg. e-grid MJ kg-1	GHG intensity w/ state e-grid kg GHG Mg-1*	Energy use w/ state e-grid MJ kg-1	N-Use Efficiency kg Grain kg-1 N	Net Energy Ratio (w/ itemized co-product credit)	g CO2e MJ-1 (w/ itemized co-product credit)	<GHG % (w/ itemized co-product credit)	Energy MJ L-1	Emissions Mg x1000 CO2e
NY	7.66	62.7	32.3	36.0	276	6.94	0.08	21.6	29.0	76.7	3.7	0.0	0.0	320	411.4	172	1495	172	1495	122.2	1.54	40	55	3.29	113.7
SD	7.53	120	40.9	12.0	0	3.15	0.08	17.7	14.0	41.1	4.7	0.5	67.7	320	551.1	173	1502	172	1502	62.5	1.54	41	54	3.30	113.8
MN	10.0	145	59.0	61.5	66	3.09	0.08	21.3	15.9	50.5	79.5	3.2	66.2	320	720.3	176	1580	177	1580	69.4	1.53	43	51	3.38	115.5
IA	10.7	144	52.5	67.4	334	5.35	0.06	21.3	11.2	43.0	67.3	0.0	41.5	320	881.3	180	1442	181	1442	73.9	1.55	45	49	3.24	116.9
WI	8.66	114	34.8	57.3	275	4.62	0.21	21.5	13.1	69.2	17.8	8.7	16.3	320	777.0	189	1551	189	1551	76.0	1.53	44	50	3.35	119.8
ND	7.22	134	47.5	11.1	0	1.98	0	19.6	19.6	42.1	66.4	0.0	0.0	320	1082.3	202	1779	202	1779	53.8	1.49	48	45	3.57	124.6
PA	7.91	103	32.2	26.0	409	7.63	0.26	19.5	15.0	60.8	14.0	0.0	0.0	320	551.6	208	1610	208	1610	76.8	1.52	44	51	3.40	126.6
IL	10.2	165	72.5	106	425	8.79	0.51	20.8	14.0	34.6	26.2	5.4	23.7	320	523.9	217	1685	217	1685	61.5	1.51	44	50	3.48	129.8
IN	9.79	164	76.0	118	410	4.59	0.41	20.4	19.6	43.0	29.9	10.1	69.9	320	951.7	224	1741	226	1741	59.8	1.50	49	45	3.53	133.2
MI	8.47	134	41.5	81.3	275	6.58	0.15	19.8	23.4	67.3	33.7	15.6	63.0	320	640.9	230	1991	230	1991	63.3	1.46	46	48	3.77	134.4
NE	9.73	146	33.8	6.0	86	6.52	0.56	18.7	19.6	116	38.3	67.4	377	320	681.8	237	2418	239	2418	66.6	1.40	47	47	4.18	137.7
CO	8.72	128	26.7	4.9	0	3.54	1.24	17.9	15.0	84.1	35.5	0.0	964.0	320	900.8	244	2653	276	2653	68.3	1.36	52	41	4.41	150.1
OH	9.54	181	66.5	88.5	392	8.60	0.13	20.7	15.0	40.2	52.4	11.5	24.7	320	807.0	246	1965	247	1965	52.7	1.46	49	45	3.75	140.5
KS	8.47	147	32.4	12.5	131	8.03	0.03	15.9	12.2	86	122	107	41.7	320	848.7	266	2698	267	2698	57.7	1.36	51	42	4.45	147.7
NC	7.16	143	34.8	86.3	403	6.22	0.05	18.3	21.5	58.0	20.6	0.0	0.0	320	552.5	273	2123	273	2123	50.1	1.44	48	45	3.90	150.0
MO	7.97	174	51.9	62.4	297	8.75	0	18.9	23.4	46.7	22.4	0.0	85.0	320	853.2	275	2252	278	2252	45.9	1.42	52	41	4.02	151.7
KY	8.79	191	73.2	86.2	389	12.2	0.06	19.4	18.7	33.7	23.4	4.7	145	320	930.3	286	2334	291	2334	46.0	1.41	53	39	4.10	156.7
GA	8.10	165	71.3	99.7	425	3.10	0.10	16.1	23.4	138.4	4.7	0.0	73.1	320	629.6	300	2397	300	2397	48.9	1.40	51	42	4.16	159.7
TX	7.78	162	42.2	5.4	0	6.78	0.12	18.0	10.3	83.2	14.0	436.2	122.0	320	667.7	356	4224	357	4224	48.1	1.19	56	37	5.91	180.1
USA	9.47	150	53.3	61.6	254	6.19	0.25	20.0	15.7	56.8	44.6	27.7	98.3	320	618.3	216	1873	216	1873	63.3	1.48	45	49	3.66	129.6

Conclusion of BESS Analysis of Life-Cycle Energy & GHG Emissions of Corn-Ethanol

1) US corn-ethanol has an energy efficiency between 1.2 and 2.1 (net energy ratio) depending on biorefinery technology and cropping efficiency. Corn Belt production is between 1.5 and 1.7 (Table 1).

2) US corn-ethanol production can reduce GHG emissions compared to gasoline by 21% to 74% depending on biorefinery technology and cropping efficiency. Corn Belt production reduces emissions in the range of 41% and 74% (Table 1).

3) Energy intensity of corn production (and GHG per Mg grain) increases from North to South, with the South having less soil organic matter, higher N inputs, and lower crop yields. Crop production is a large contributor of life-cycle emissions (Table 2), and its variation provides a GHG reduction between 37% and 55% by state compared to gasoline, assuming a consistent natural gas powered ethanol biorefinery (Fig. 2).

4) Co-product credits have a large influence on energy efficiency and GHG reduction potential and must be defined accurately (Table 2). BESS provides a dynamic co-product credit based on substitution of corn and urea in cattle diets; extension of BESS to include options for use of co-products in swine and poultry diets (or as direct fuel) is also needed.

5) Aggressive Renewable Fuel Standards in some states and regions may require certification of biofuel GHG-intensity for import into those markets. Likewise, the ethanol industry could gain additional income from a cap-and-trade GHG emissions trading market. The BESS model provides a framework for a certification system (Fig. 1), (Liska 2007, McElroy, 2007).

References

Supporting data and references, see BESS *User's Guide*, www.bess.unl.edu

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