

# A User-Friendly Simulation Tool for Estimating Carbon Credits for Corn-Ethanol Systems

Adam J. Liska<sup>1\*</sup>, Haishun Yang<sup>1</sup>, Daniel T. Walters<sup>1</sup>,  
Virgil Bremer<sup>2</sup>, Galen Erickson<sup>2</sup>, Terry  
Klopfenstein<sup>2</sup>, Rick Koelsch<sup>3</sup>, Dan Kenney<sup>5</sup>, and  
Patrick Tracy<sup>5</sup>, Kenneth G. Cassman<sup>1,4</sup>

Department of Agronomy and Horticulture<sup>1</sup>, Department  
of Animal Science<sup>2</sup>, Department of Biological System  
Engineering<sup>3</sup>, Nebraska Center for Energy Sciences  
Research<sup>4</sup>,

University of Nebraska-Lincoln;  
PRIME Biosolutions<sup>5</sup>, Omaha, Nebraska.

\* [aliska2@unl.edu](mailto:aliska2@unl.edu), [www.bess.unl.edu](http://www.bess.unl.edu), [www.unl.edu](http://www.unl.edu),

# Options for promoting low C-cost biofuels and net GHG reductions

---

- 1) Low C-cost certification for import to specific RFS markets (e.g. CA, European Union)
- 2) Linking biofuel subsidies and tax credits to low C-cost certification and net GHG reduction
- 3) Emissions trading: a market-based scheme for environmental improvement that allows parties to buy permits for GHG emissions or sell credits for reductions in emissions of certain pollutants
  - European Union's "Emissions Trading Scheme" (ETS) began in 2005, consistent with goals of the Kyoto Protocol
  - US policy makers are discussing options for regulating emissions and establishing carbon/emissions trading schemes

# Cap-and-Trade Mechanism

---

- An emissions limit is set for an industry sector (electricity, oil refineries, etc.); usually set through negotiation
- Emissions allowances allocated to participating entities; allowances provided without cost, auctioned, or sold at a set price
- Businesses that can reduce emissions below their allocated amount can sell their credits to businesses that emit more than their allotment
- Estimated value of GHG emissions allowances in the USA is \$50-\$300 billion dollars by 2020 (US Congressional Budget Office 2007)

# Emissions Trading by the Biofuel Industry

---

- On average, corn grain-ethanol production is estimated to reduce net GHG emissions by 13% compared to gasoline (Farrell *et al.* 2006)
- But, there is a wide range in net GHG emissions reductions among individual ethanol facilities
- Therefore, a user-friendly certification software is needed that can evaluate individual ethanol facilities to estimate life-cycle emissions from ethanol biorefineries and their associated feedstock supply to determine emissions savings relative to gasoline
- Lack of accurate models and certification tools has inhibited the European ETS (Ellerman 2007)

# Certification Software

---

- Requirements of C-cost/GHG certification software for the biofuel industry
  - Transparent framework and assumptions
  - User-friendly graphic interface and generation of certification report
  - Default values for key inputs and conversion efficiencies based on best current estimates with full documentation
  - Flexibility to substitute customized values for an individual ethanol facility based on energy sources, co-product processing, and feedstock production parameters (e.g. corn yield and input rates—fertilizer, irrigation, tillage, etc)

# BESS\* Model for Emissions Trading

---

BESS Life-Cycle Model includes 4 components:

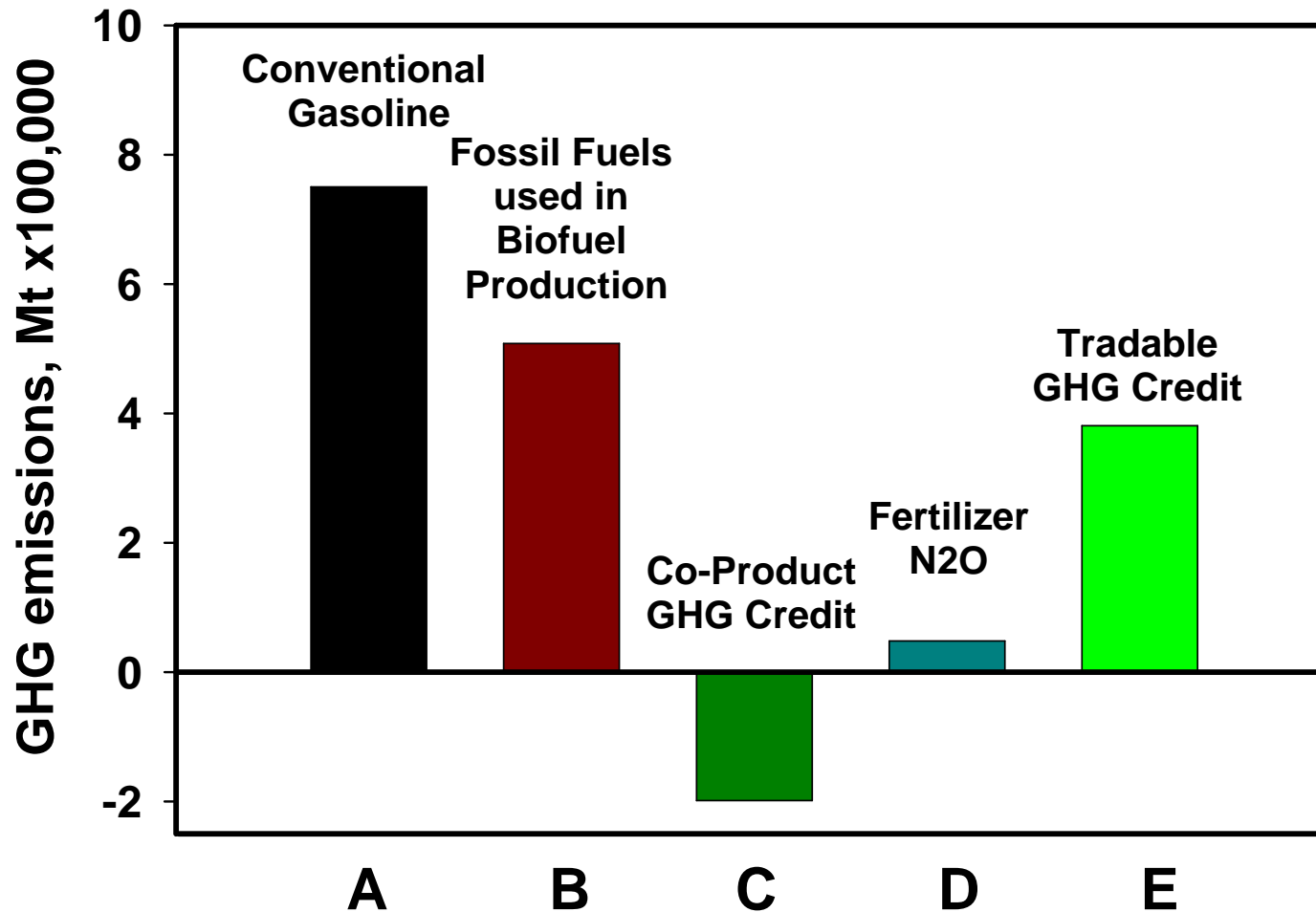
- Crop production
- Ethanol biorefinery
- Cattle feedlot for feeding distiller's grains
- Anaerobic digestion unit (optional, closed-loop facility)

Three types of life-cycle analysis:

- Energy analysis—life-cycle net energy yield/efficiency
- Emissions analysis—net carbon dioxide (CO<sub>2</sub>) and trace greenhouse gases (CH<sub>4</sub>, N<sub>2</sub>O), and global warming potential (GWP)
- Resource Requirements—crop production area, grain, water, fossil fuels (petroleum, nat. gas, and coal)

\*Funding for BESS development from the Western Governor's Assoc.

$$\text{Tradable GHG Credit (E)} = A - B - C - D$$



C = co-products displace corn grain and urea in cattle diets provide energy savings

Open a scenario

2, NE Average.stg

Scenario description

CROP PRODUCTION

Corn production

Ethanol biorefinery

Cattle feedlot

Productivity

Corn grain (dry matter), Mg/ha

Soil C sequestration, Mg C/ha

Material inputs

Nitrogen, kg N/ha

Phosphorus, kg P2O5/ha

Potassium, kg K2O/ha

Lime, kg/ha

Herbicides, kg/ha

Insecticides, kg/ha

Seed, kg/ha

Energy inputs

Aggregate energy inputs

Gasoline, L/ha

Diesel, L/ha

LPG, L/ha

Natural gas, m3/ha

Electricity, kWh/ha

Depeciable capital energy, MJ/ha

Itemized energy inputs

Tillage  Diesel  L/ha

Irrigation  Diesel  cm

Combine harvest Diesel  L/ha

Grain drying Natural gas  m3/ha

**Compute**

Note: all settings refer to annual values

Open a scenario

2, NE Average.stg

Scenario description

CROP PRODUCTION

Corn production

Ethanol biorefinery

Cattle feedlot

Ethanol production, million L 100

Corn-to-ethanol conversion rate, L/kg 0.399

Energy use

Co-product output type Dry DGS

Source of thermal energy Natural gas

Thermal energy for ethanol production

Thermal energy for drying DG

Electricity input, k

Depreciable Energy Input, MJ/L 0.13

Water use, L/L ethanol 4.7

Co-product production

Proportion of DG, % Dry DG 0

Modified DG 0

Wet DG

DDGS-Equivalent (90% DM), kg/L 0.8

DDGS-Equivalent (100% DM), kg/L 0.72

DDG-Equivalent (100% DM), kg/L 0.58

Compute

Note: all settings refer to annual values

Input: Operation settings
Output: Individual scenarios
Output: Life-cycle scenario comparison
Parameters

Crop production
Ethanol biorefinery
Cattle feedlot
LC analysis
LC emissions
GHG credit
Summary report

Show results of 2, NE Average.stg

Annual requirements

25.8	Total harvest area, x1000 ha
250627	Total grain requirement, Mg
62010.7	Water use, million L

To plot

- Amount of FF energy
- % in crop production
- % in life cycle

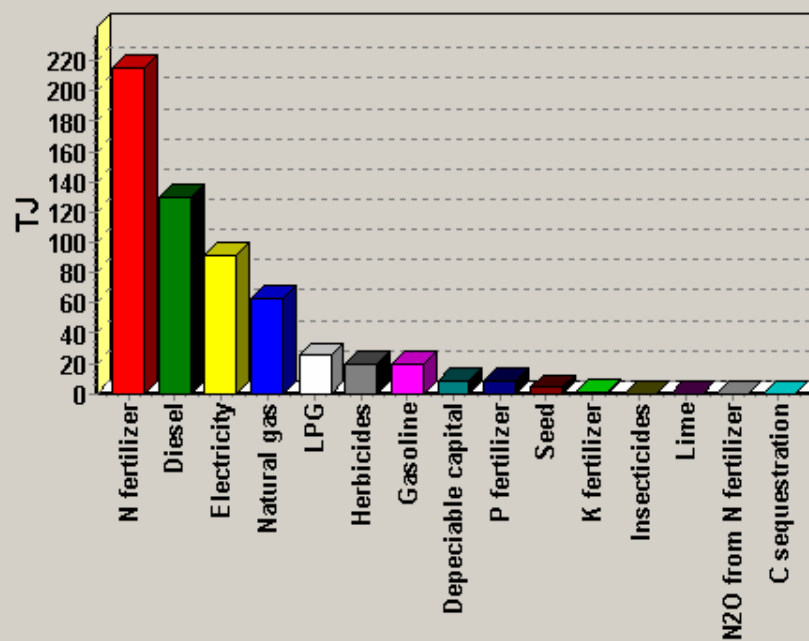
Enlarge

Pie chart / Bar chart

Fossil fuel energy

Material input		Amount, T.J	% in crop production	% in life cycle
N fertilizer	3777.5 Mg	215	36.7	12.0
P fertilizer	873.3 Mg	8.1	1.4	0.5
K fertilizer	155.0 Mg	1.1	0.2	0.1
Lime	0.0 Mg	0.0	0.0	0.0
Herbicides	56.8 Mg	20.2	3.4	1.1
Insecticides	1.3 Mg	0.5	0.1	0.0
Seed	483.2 Mg	4.7	0.8	0.3
Gasoline	506.4 x1000 L	20.0	3.4	1.1
Diesel	2994.6 x1000 L	129	22.0	7.2
LPG	989.6 x1000 L	25.7	4.4	1.4
Natural gas	1741.5 x1000 m3	63.0	10.8	3.5
Electricity	9.7 million kWh	91.0	15.5	5.1
Depeccial		8.3	1.4	0.5
N2O from N fertilizer				
C sequestration				
<b>Total</b>		<b>586</b>	<b>100.0</b>	<b>32.7</b>

Fossil fuel energy



Input: Operation settings **Output: Individual scenarios** Output: Life-cycle scenario comparison Parameters

Crop production Ethanol biorefinery Cattle feedlot **LC analysis** LC emissions GHG credit Summary report

Show results of 2, NE Average.stg

Crop production / ethanol biorefinery per year

250.6	Annual corn requirement, Mg
25.8	Total harvest area, x1000 ha
3870.0	Ethanol yield per area, L/ha
58000.0	Dry distillers grains production, Mg DM
470.0	Total water usage, million L

Water use per year

	Amount, million L	% in total
Crop production	62010.7	99.2
Ethanol biorefinery	470.0	0.8
Cattle feedlot	0.0	0.0
Biodigester	0.0	0.0
Others	0.0	0.0
Total	62480.7	100.0

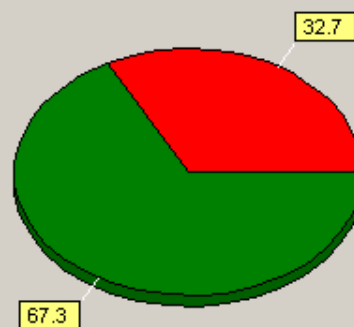
% in life-cycle energy input & output

Input	
32.7	Corn production
67.3	Biorefinery
Output	
83.6	Ethanol
16.4	Co-product credit

Energy balance & efficiency

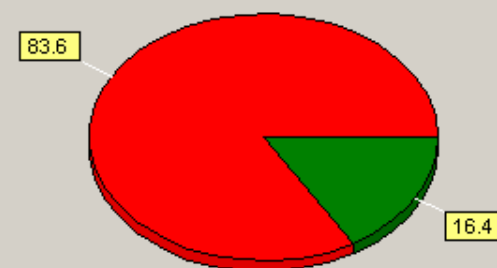
1792	Total gross energy input, TJ
413	Energy credit in coproducts & biogas, TJ
2205	Total net energy input, TJ
2110	Energy output in ethanol, TJ
17.9	Energy input per ethanol production, MJ/L
2523	Total energy output (ethanol + credit), TJ
1.4	Net Energy Ratio, output:input
3.2	Net Energy Value, MJ/L
12295	Net Energy Yield, MJ/ha
7.9	Ethanol : Petroleum ratio (MJ/MJ)

Life-cycle energy input, %



Energy input to corn production  
Energy input to biorefinery

Life-cycle energy output, %



Energy output in ethanol  
Energy output in co-products

Input: Operation settings **Output: Individual scenarios** Output: Life-cycle scenario comparison Parameters

Crop production Ethanol biorefinery Cattle feedlot LC analysis **LC emissions** GHG credit Summary report

Show results of 2, NE Average.stg

Life-cycle emissions, Mg/year

Absolute, Mg	CO2	CH4	N2O	GWP
Crop	38444.5	5.8	41.8	50954.0
Biorefinery	76362.7	1.4	0.6	77007.4
Feedlot	-52500.0	0.0	0.0	-52500.0
Total	62307.3	7.2	42.4	75461.5

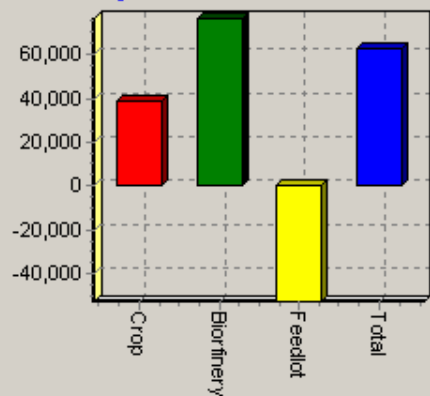
% in life cycle	CO2	CH4	N2O	GWP
Crop	33.5	80.4	98.6	39.8
Biorefinery	66.5	19.6	1.4	102.0

Credit included

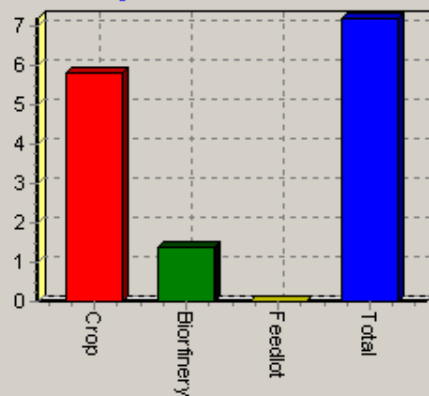
To plot

Absolute amount, Mg  Relative in in life cycle total, %

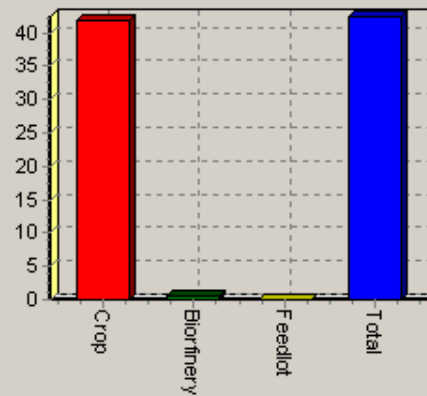
Life-cycle CO2 emissions



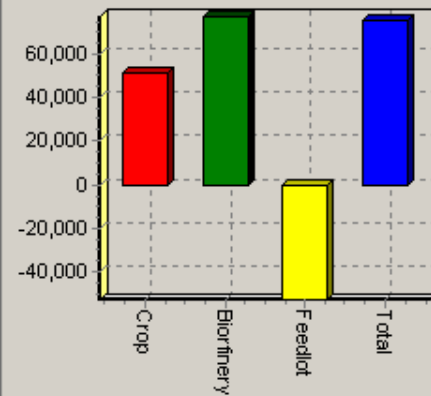
Life-cycle CH4 emissions



Life-cycle N2O emissions



Life-cycle GWP emissions



Input: Operation settings **Output: Individual scenarios** Output: Life-cycle scenario comparison Parameters

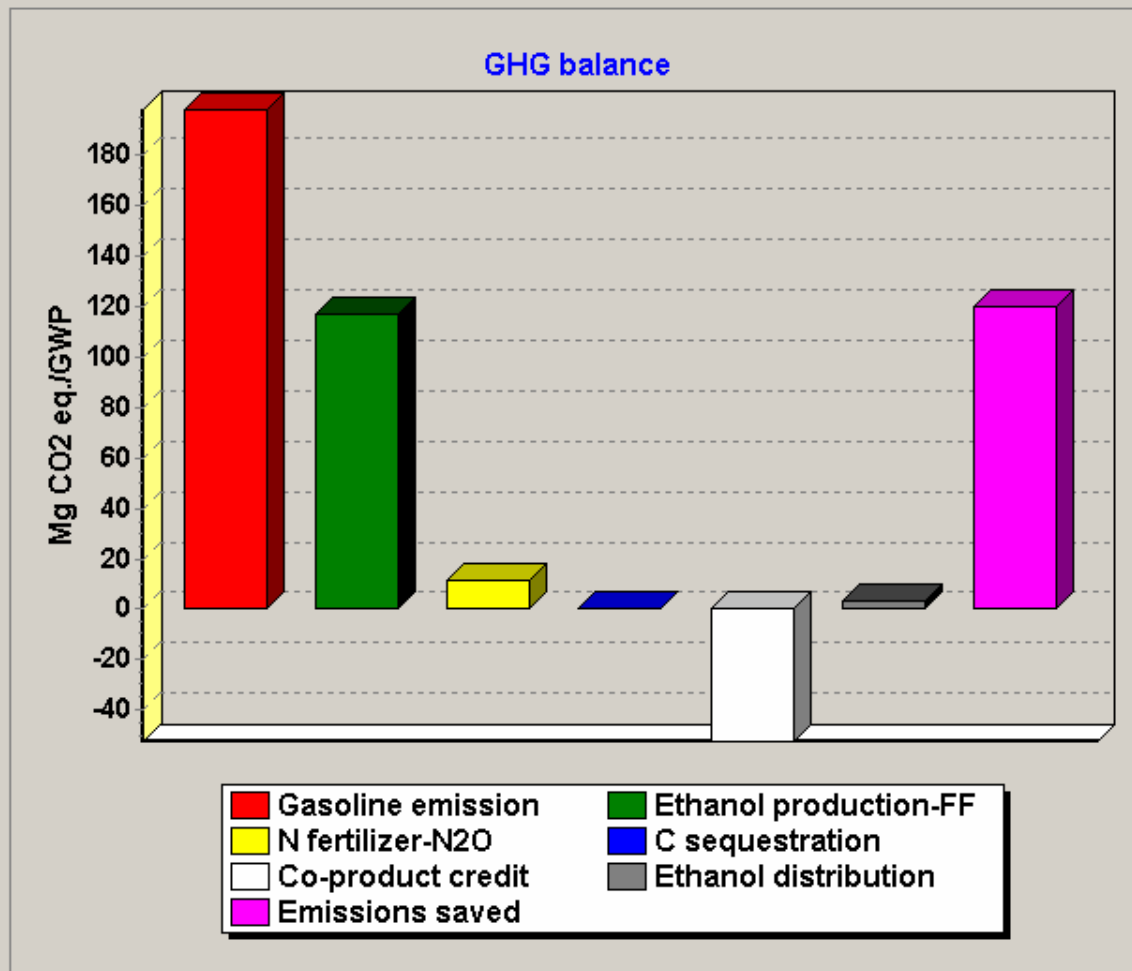
Crop production Ethanol biorefinery Cattle feedlot LC analysis LC emissions **GHG credit** Summary report

Show results of 2, NE Average.stg

To plot  
 CO2  
 CO2eq./GWP

GHG emissions and credit per year

Emission, Mg/year	CO2	CO2eq./GWP
Gasoline total emission	189.7	198.2
Ethanol production-FF	114.8	116.8
N fertilizer-N2O	0.0	11.2
Carbon sequestration	0.0	0.0
Co-product credit	-52.5	-52.5
Ethanol distribution	3.0	3.0
Emissions saved	124.5	119.8
Difference, %	65.6	60.4
Emissions offset credit, x1000 \$	497.9	479.1



Input: Operation settings **Output: Individual scenarios** Output: Life-cycle scenario comparison Parameters

Crop production Ethanol biorefinery Cattle feedlot LC analysis LC emissions GHG credit **Summary report**

Show results of 2, NE Average.stg

Editing allowed

Load to MS Excel

1						
2	RESULT SUMMARY	Input setting file is:	2, NE Average.stg			
3						
4	Crop performance					
5		Harvest area	ha	25838		
6		Grain use	Mg	250627		
7						
8	Material inputs					
9		Nitrogen fertilizer	kg	3777485		
10		Phosphorus fertilizer	kg	873317		
11		Potassium fertilizer	kg	155027		
12		Lime	kg	0.0		
13		Herbicides	kg	56843		
14		Insecticides	kg	1292		
15		Seed	kg	483167		
16	Aggregate energy Inp	Aggregate energy Inp				
17		Gasoline	L	506421		
18		Diesel	L	2994600		
19		LPG	L	989587		
20		Natural Gas	m3	1741467		
21		Electricity	kWh	9733096		
22	Total water use, L			6.201069685E10		
23						
24	Energy inputs		Amount	% in crop	% in life cycle	
25		Nitrogen Fertilizer	215	36.7	12.0	
26		Phosphorus Fertilizer	8.1	1.4	0.5	
27		Potassium Fertilizer	1.1	0.2	0.1	
28		Lime	0.0	0.0	0.0	
29		Herbicides	20.2	3.4	1.1	
30		Insecticides	0.5	0.1	0.0	
31		Seed	4.7	0.8	0.3	

# Sample of BESS LCA runs: Crop Production

---

		<b>US Avg.</b>	<b>NE Avg.</b>	<b>IA Avg.</b>	<b>Adv. Irr.</b>
<b>Grain Yield</b>	<b>Mg ha-1</b>	<b>8.75</b>	<b>9.75</b>	<b>10.69</b>	<b>13.71</b>
<b>N Fertilizer</b>	<b>kg N ha-1</b>	<b>150</b>	<b>146</b>	<b>145</b>	<b>177</b>
<b>P Fertilizer</b>	<b>kg P2O5 ha-1</b>	<b>64</b>	<b>34</b>	<b>53</b>	<b>-</b>
<b>K Fertilizer</b>	<b>kg K2O ha-1</b>	<b>99</b>	<b>6</b>	<b>68</b>	<b>-</b>
<b>Lime</b>	<b>kg ha-1</b>	<b>1,121</b>	<b>-</b>	<b>-</b>	<b>-</b>
<b>Herbicides</b>	<b>kg ha-1</b>	<b>2.8</b>	<b>2.2</b>	<b>1.9</b>	<b>2.2</b>
<b>Insecticides</b>	<b>kg ha-1</b>	<b>0.2</b>	<b>0.1</b>	<b>0.0</b>	<b>0.2</b>
<b>Seed</b>	<b>kg ha-1</b>	<b>24</b>	<b>19</b>	<b>21</b>	<b>30</b>
<b>Gasoline</b>	<b>L ha-1</b>	<b>32</b>	<b>20</b>	<b>11</b>	<b>-</b>
<b>Diesel</b>	<b>L ha-1</b>	<b>63</b>	<b>116</b>	<b>43</b>	<b>40</b>
<b>LPG</b>	<b>L ha-1</b>	<b>30</b>	<b>38</b>	<b>67</b>	<b>-</b>
<b>Natural Gas</b>	<b>m3 ha-1</b>	<b>19</b>	<b>67</b>	<b>-</b>	<b>-</b>
<b>Electricity</b>	<b>kWh ha-1</b>	<b>88</b>	<b>377</b>	<b>41</b>	<b>1332</b>

# BESS LCA results: Net Energy Ratio

## Corn Production System

Ethanol Biorefineries

	USA average	NE average	Iowa average	Advanced Irrigated
coal	1.39	1.33	1.52	1.42
natural gas	1.47	1.41	1.62	1.51
natural gas, wet DG	1.80	1.71	2.03	1.85
closed-loop facility	2.36	2.20	2.78	2.45

# GHG Emissions Reduction (% , Mt CO<sub>2</sub>eq\*)

## Corn Production System

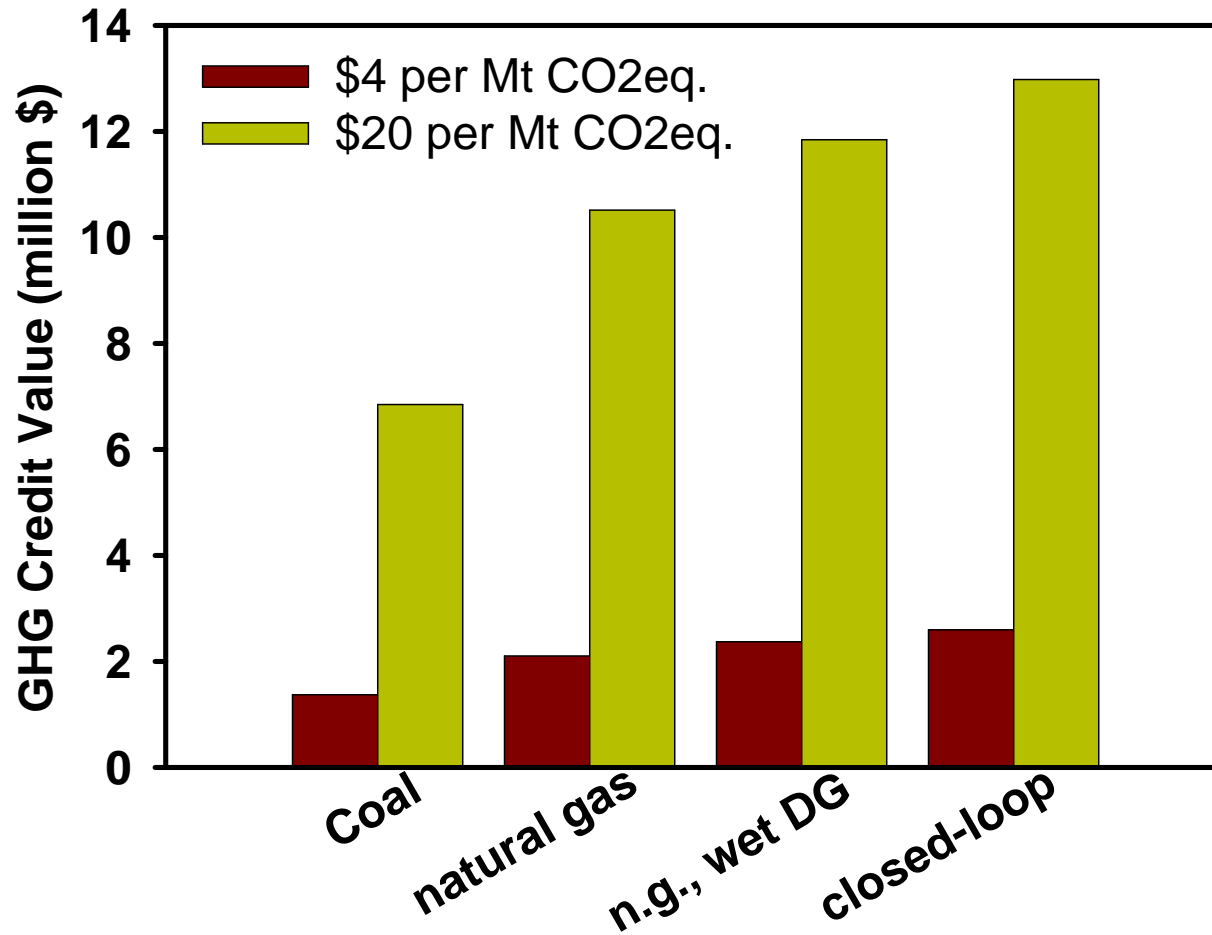
Ethanol Biorefineries

	USA average	NE average	Iowa average	Advanced Irrigated
coal	26%, 197,817	36%, 270,668	46%, 342,359	39%, 294,171
natural gas	51%, 381,213	61%, 454,064	70%, 525,756	63%, 477,567
natural gas, wet DG	60%, 447,462	69%, 520,313	79%, 592,004	73%, 543,816
closed-loop facility	67%, 504,269	77%, 577,120	87%, 648,812	80%, 600,623

\*Based on a 100 million gal yr<sup>-1</sup> production capacity

# GHG Emissions Trading Credit (\$)

---



\*Based on a 100 million gal yr<sup>-1</sup> production capacity in IA; fermentation CO<sub>2</sub> not included (neutral); \$4 per metric ton CO<sub>2</sub>, Dec. 2006, Chicago Climate Exchange

# Conclusions

---

- The quantity of life-cycle emissions reductions from corn-ethanol is dependent on biorefinery energy efficiency and cropping system performance, which is specific for individual biorefineries and regions.
- Co-product processing and use are important factors for determining corn-ethanol's life-cycle energy efficiency and emissions trading credits
- The BESS certification software provides a standardized framework that has the flexibility to include key parameters for determining emissions reductions for specific corn-ethanol facilities
- Certification software will require accreditation by industry and GHG emissions trading institutions, which will require agreement on assumptions, default values, input parameters, and system boundaries

# Support for BESS Development

---

- Western Governor's Association
- Nebraska Energy Office
- University of Nebraska-Lincoln,  
Institute of Agriculture and Natural  
Resources
- Nebraska Center for Energy Sciences  
Research

BESS software will be released on July 20<sup>th</sup>, 2007  
Software will be freely available from the BESS website:

[www.bess.unl.edu](http://www.bess.unl.edu)

# Related References

---

- Chicago Climate Exchange, [www.chicagoclimatex.com](http://www.chicagoclimatex.com)
- Ellerman A.D., & Buchner B.K. (2007). The European Union Emissions Trading Scheme: Origins, Allocation, and Early Results. *Review of Environmental Economics and Policy*, 1, 66-87
- Energy and Environmental Analysis, Inc. *Baseline Energy Consumption Estimates for Natural Gas and Coal-based Ethanol Plants—The Potential Impact of Combined Heat and Power (CHP)*. Combined Heat and Power Partnership of the U.S. Environmental Protection Agency.
- Farrell A.E., Plevin R.J., Turner B.T., Jones A.D., O'Hare M. & Kammen D.M. (2006). Ethanol can contribute to energy and environmental goals. *Science*, 311, 506-508.
- Penam J., Gytarsky M., Hiraishi T., Irving W., Krug T. (2006) *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Intergovernmental Panel on Climate Change, National Greenhouse Gas Inventories Programme, [www.ipcc-nggip.iges.or.jp/public/2006gl/](http://www.ipcc-nggip.iges.or.jp/public/2006gl/)
- US Congressional Budget Office (2007). *Trade-offs in allocating allowances for CO2 emissions*. [www.cbo.gov/ftpdocs/80xx/doc8027/04-25-Cap\\_Trade.pdf](http://www.cbo.gov/ftpdocs/80xx/doc8027/04-25-Cap_Trade.pdf)
- Wang M., Wu M., & Huo H. (2007). Life-cycle energy and greenhouse gas emission impacts of different corn ethanol plant types. *Environmental Research Letters*, 2, 024001 (13p)
- Yamin, Farhana (2006). *Climate Change and Carbon Markets*. Earthscan, London