BESS Model (www.bess.unl.edu): *B*iofuel *E*nergy *S*ystems *S*imulator

Current capabilities: corn-ethanol

Adam J. Liska[1], Haishun S. Yang[1], Daniel T. Walters[1], Virgil Bremer[2], Galen Erickson[2], Terry Klopfenstein[2], Rick Koelsch[3], Dan Kenney[5], and Patrick Tracy[5], Kenneth G. Cassman[1,4]

Department of Agronomy and Horticulture[1], Department of Animal Science[2], Department of Biological System Engineering[3], Nebraska Center for Energy Sciences Research[4], University of Nebraska-Lincoln;

PRIME Biosolutions[5], Omaha, Nebraska.

kcassman1@unl.edu, aliska2@unl.edu

BESS characteristics and capabilities as LCFS certification software

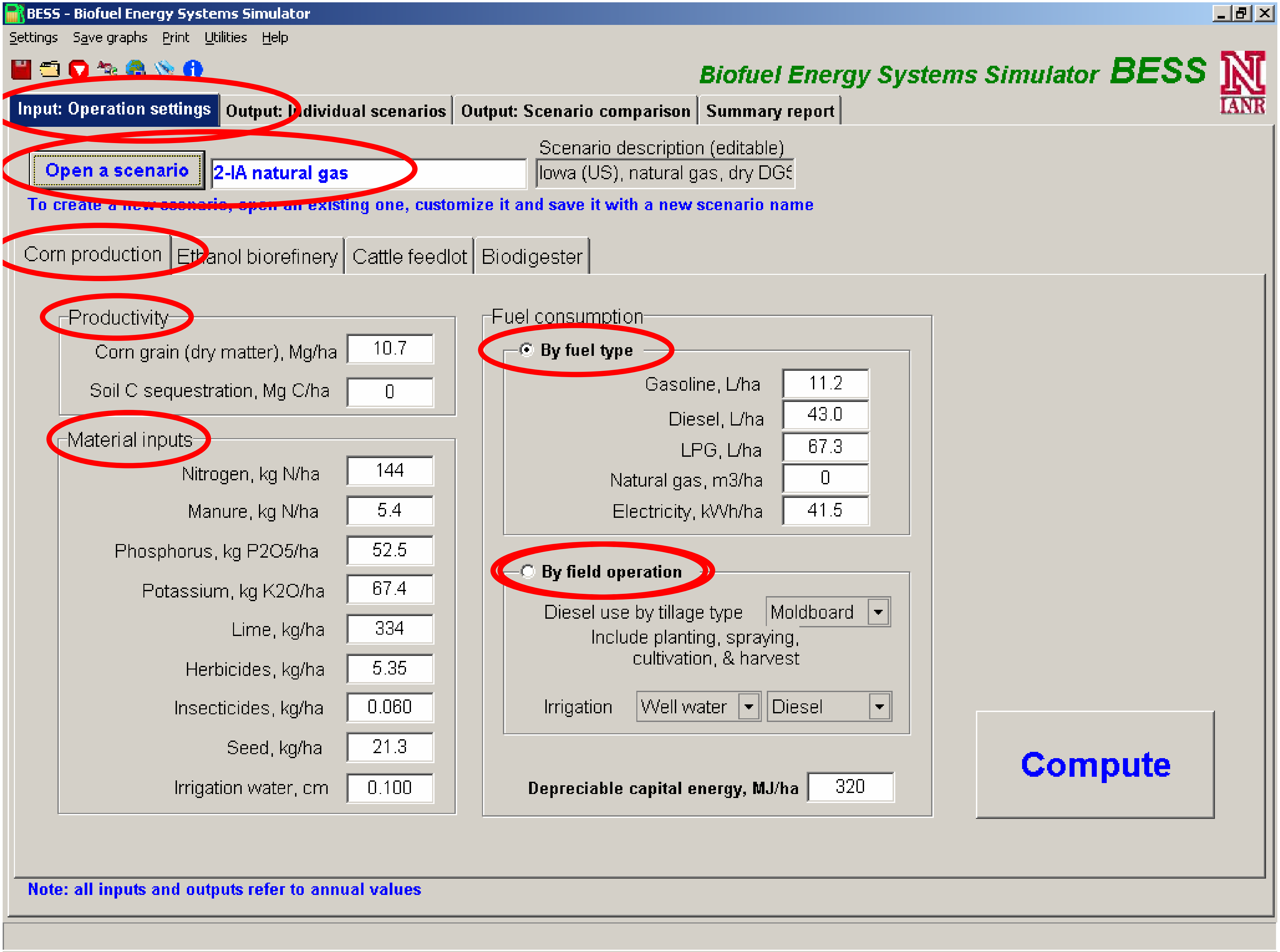
- Assessment of an individual biorefinery with specified ethanol production capacity, feedstock supply, and ethanol plant design/performance
- Life-cycle GHG emissions, energy yields, natural resource requirements (water, N fertilizer, land)
- User-friendly graphic interface
- Transparent default parameters, updated to include most recent estimates of biorefinery efficiency, crop yields and inputs, co-product utilization credits
- Summary report shows all input parameters and output metrics; compares performance metrics with default values for documentation and certification

Comparison of LCA Models

	GREET	EBAMM	BESS
Boundaries	"Seed-to-tailpipe" different fuel types	"Seed-to-fuel" generic	"Seed-to-fuel" generic or individual biorefinery
Interface	Graphic	Spreadsheet	User-friendly graphic
Transparency	Opaque, "cryptic" modifiable	Accessible, modifiable	Accessible, modifiable
Underpinning equations	Widely used, modifiable equations	Similar to GREET, modifiable equations	Similar to **GREET/EBAMM,** with new co-product credit scheme, fixed equations

Importance of crop production and co-product credits to corn-ethanol life-cycle assessments

- GHG emissions from corn production account for 40-65% of life-cycle emissions, depending on biorefinery location, design, and processing of co-products
  - Need for agronomic science from production-scale research to accurately estimate carbon intensity and GHG accounting (Verma et al, 2005; Adviento-Borbe et al, 2007; Duvick and Cassman, 1999)
- Co-product credit for feeding distillers grains accounts for offset of 20-40% of life-cycle emissions, depending on co-product processing and utilization.
  - Need for animal science input to ensure accuracy of co-product credits (Klopfenstein et al 2008)


BESS - Biofuel Energy Systems Simulator
Settings Save graphs Print Utilities Help
Biofuel Energy Systems Simulator BESS
IANR
Input: Operation settings
Output: Individual scenarios
Output: Scenario comparison
Summary report
Open a scenario
2-IA natural gas
Scenario description (editable)
Iowa (US), natural gas, dry DGS
To create a new scenario, open an existing one, customize it and save it with a new scenario name
Corn production
Ethanol biorefinery
Cattle feedlot
Biodigester
Productivity
Corn grain (dry matter), Mg/ha 10.7
Soil C sequestration, Mg C/ha 0
Material inputs
Nitrogen, kg N/ha 144
Manure, kg N/ha 5.4
Phosphorus, kg P2O5/ha 52.5
Potassium, kg K2O/ha 67.4
Lime, kg/ha 334
Herbicides, kg/ha 5.35
Insecticides, kg/ha 0.060
Seed, kg/ha 21.3
Irrigation water, cm 0.100
Fuel consumption
By fuel type
Gasoline, L/ha 11.2
Diesel, L/ha 43.0
LPG, L/ha 67.3
Natural gas, m3/ha 0
Electricity, kWh/ha 41.5
By field operation
Diesel use by tillage type Moldboard
Include planting, spraying, cultivation, & harvest
Irrigation Well water Diesel
Depreciable capital energy, MJ/ha 320
Compute
Note: all inputs and outputs refer to annual values

BESS - Biofuel Energy Systems Simulator

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Biofuel Energy Systems Simulator BESS

Input: Operation settings | **Output: Individual scenarios** | Output: Scenario comparison | Summary report

Crop production | Ethanol biorefinery | Cattle feedlot | LC analysis | LC emissions | GHG emissions credit

Show results of scenario (A) 2-IA natural gas — Iowa (US), natural gas, dry DGS

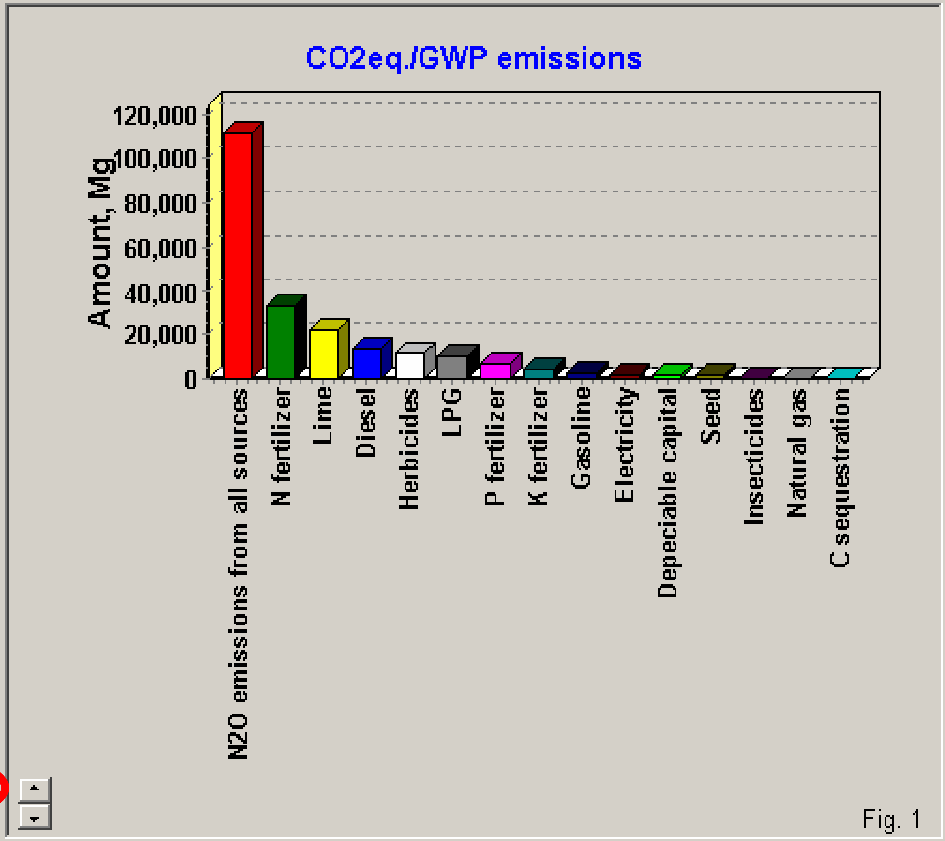
Total harvest area, x1000 ha	88.8	1,443	Energy use rate, MJ/Mg grain
Total grain requirement, Mg	949,875		
Water use, million L	888	234	GHG intensity, kg CO2 eq./Mg grain

Pie / Bar chart

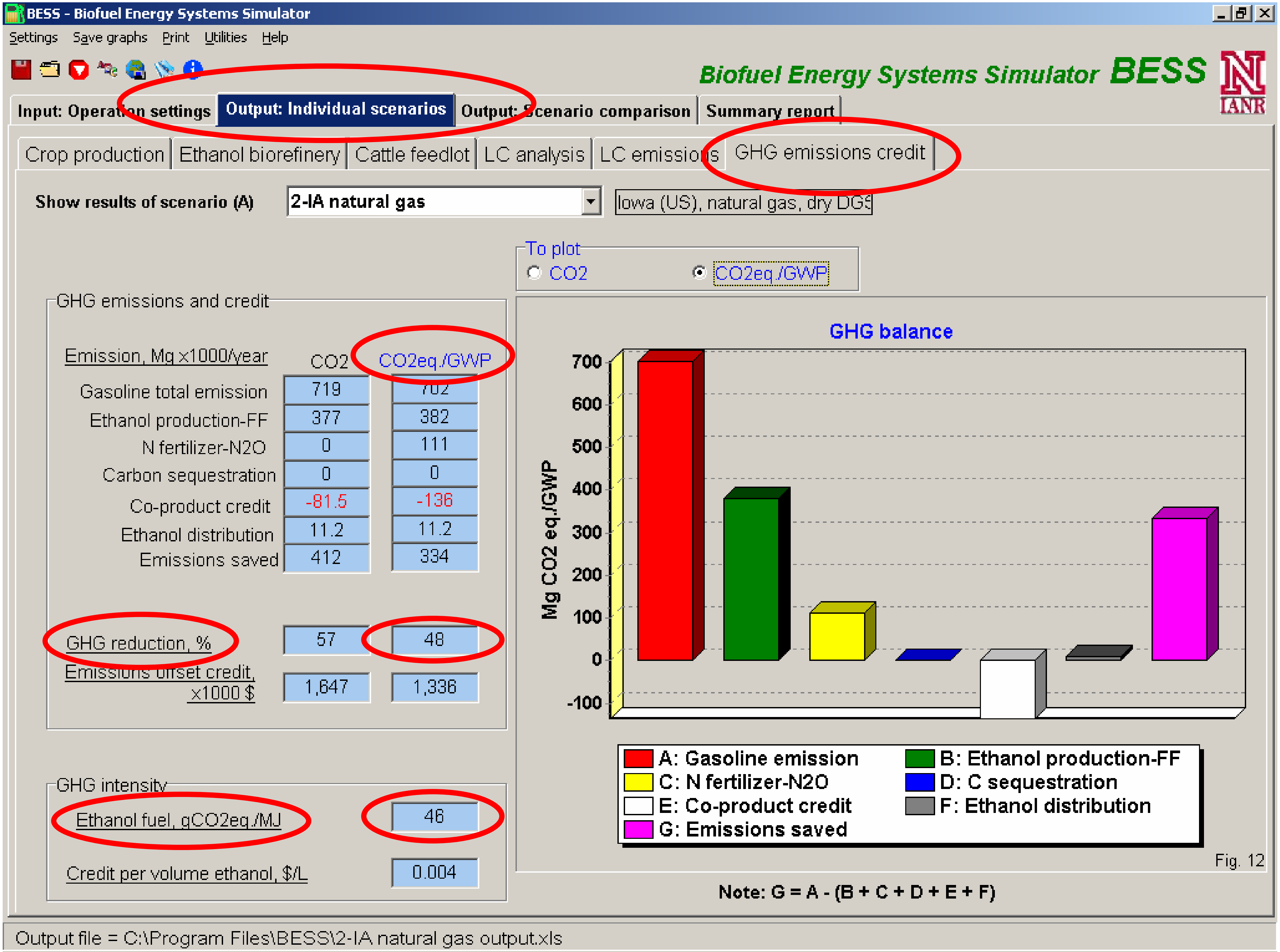
To plot: ● Absolute amount ○ % in crop production ○ % in life cycle total

CO2eq./GWP emissions

Material input			Amount, Mg	% in crop production	% in life cycle
N fertilizer	12,783	Mg	33,109	15	6.7
P fertilizer	4,661	Mg	7,504	3.4	1.5
K fertilizer	5,983	Mg	4,272	1.9	0.9
Lime	29,650	Mg	22,238	10.0	4.5
Herbicides	475	Mg	11,897	5.4	2.4
Insecticides	5.30	Mg	138	0.1	0.0
Seed	1,891	Mg	1,517	0.7	0.3
Gasoline	994	x1000 L	2,794	1.3	0.6
Diesel	3,839	x1000 L	13,640	6.1	2.8
LPG	5,974	x1000 L	9,767	4.4	2.0
Natural gas	0	x1000 m3	0	0.0	0.0
Electricity	3,684	MWh	2,278	1.0	0.5
Depeciable capital			2,112	1.0	0.4
N2O emissions from all sources			110,857	50	23
C sequestration			0	0.0	0.0
Total			222,123	100	45



Output file = C:\Program Files\BESS\2-IA natural gas output.xls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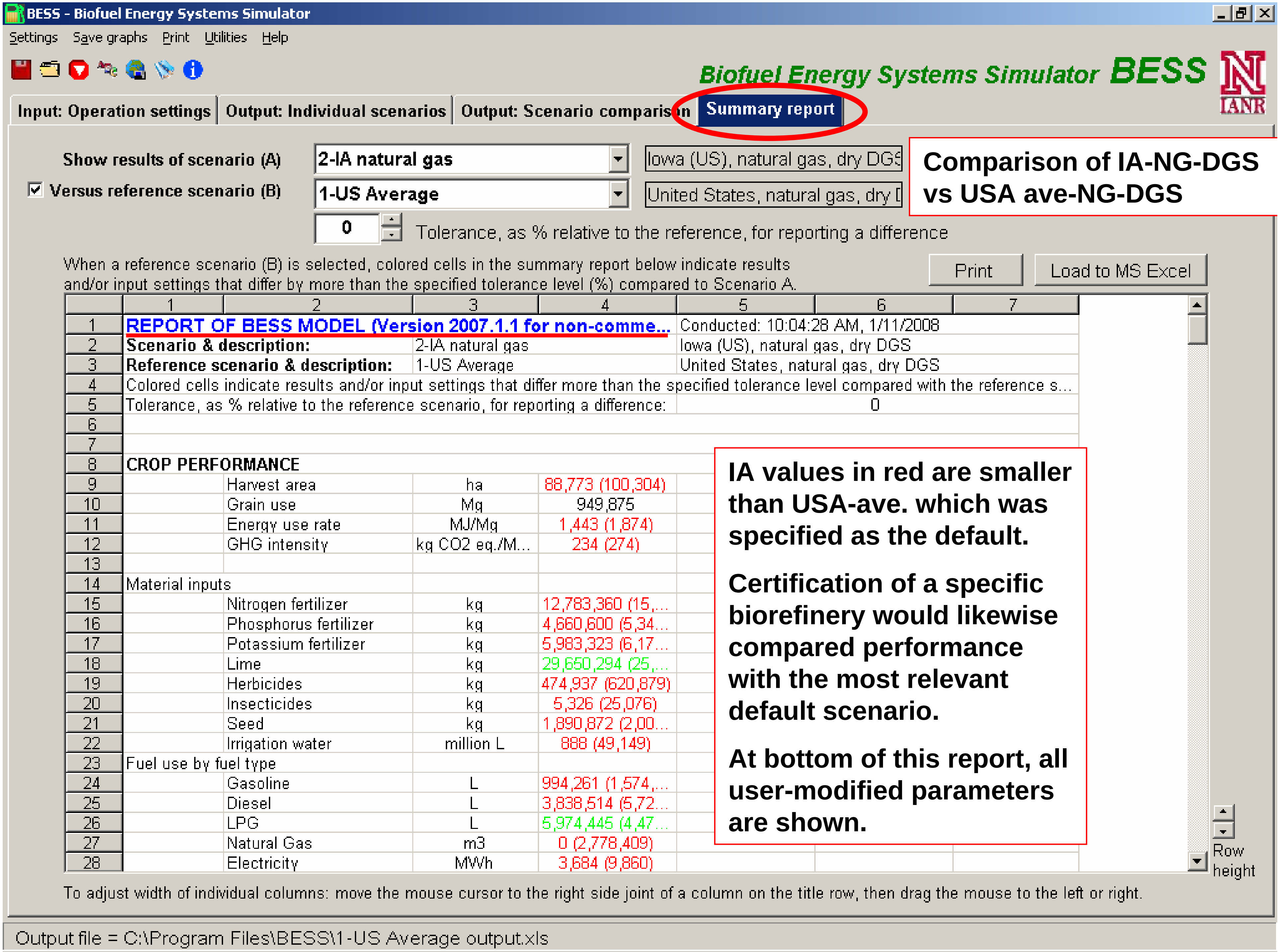
GHG emissions credit
Show results of scenario (A)
2-IA natural gas
Iowa (US), natural gas, dry DGS
To plot
CO2
CO2eq./GWP
GHG emissions and credit
Emission, Mg x1000/year
CO2
CO2eq./GWP
Gasoline total emission 719 702
Ethanol production-FF 377 382
N fertilizer-N2O 0 111
Carbon sequestration 0 0
Co-product credit -81.5 -136
Ethanol distribution 11.2 11.2
Emissions saved 412 334
GHG reduction, % 57 48
Emissions offset credit, x1000 $ 1,647 1,336
GHG intensity
Ethanol fuel, gCO2eq./MJ 46
Credit per volume ethanol, $/L 0.004
GHG balance
Mg CO2 eq./GWP
700
600
500
400
300
200
100
0
-100
A: Gasoline emission
B: Ethanol production-FF
C: N fertilizer-N2O
D: C sequestration
E: Co-product credit
F: Ethanol distribution
G: Emissions saved
Fig. 12
Note: G = A - (B + C + D + E + F)
Output file = C:\Program Files\BESS\2-IA natural gas output.xls



Comparison of IA-NG-DGS vs USA ave-NG-DGS

IA values in red are smaller than USA-ave. which was specified as the default.

Certification of a specific biorefinery would likewise compared performance with the most relevant default scenario.

At bottom of this report, all user-modified parameters are shown.

BESS User's Guide: version 2008.2.0 1

BESS:

*B*iofuel *E*nergy *S*ystems *S*imulator

Life-Cycle Energy & Emissions Analysis Model for Corn-Ethanol Biofuel Production Systems

User's Guide for BESS Software

Adam J. Liska, Haishun S. Yang, Daniel T. Walters, Kenneth G. Cassman
Department of Agronomy and Horticulture, IANR
University of Nebraska-Lincoln
http://www.agronomy.unl.edu/

Terry Klopfenstein, Galen Erickson, Virgil Bremer
Department of Animal Science, IANR
University of Nebraska-Lincoln
http://www.animalscience.unl.edu/

Rick Koelsch
Department of Biological Systems Engineering, IANR
University of Nebraska-Lincoln
http://bse.unl.edu/

Dan Kenney and Patrick Tracy
PRIME Biosolutions, Omaha, Nebraska
http://www.primebiosolutions.com/

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User's Guide

--Detailed description of model capabilities, equations, assumptions behind default values

--pdf file in model under help drop-down menu

--57 pages of text, screenshots, and 80 references that document the sources for all assumptions and default values

BESS Model, vers. 2008.2.0

Default Reference Scenarios:

Methods and Results

Input data for BESS default scenarios

Corn Production

- USDA-ERS *ARMS* crop inputs 2005; energy inputs from 2001

  (Surveys of corn production energy inputs no longer conducted - William McBride, USDA-ERS)
- USDA-NASS state crop yields, 3-yr average, 2003-2005
- UNL production-scale data, irrigated corn for high-yield progressive scenario (Verma et al, 2005)

Biorefinery

- EPA 2006, *Baseline Energy Consumption Estimates for Natural Gas and Coal-based Ethanol Plants.*
- *USDA's 2002 ethanol cost-of-production survey* (Shapouri, 2005).
- PrimeBiosolutions, Mead NE, closed-loop biorefinery system

Co-product cattle feeding: Klopfenstein, 2008

Greenhouse Gas Emission factors

- *IPCC 2006 Guidelines for National Greenhouse Gas Inventories.*
- EPA, *e-grid 2004,* state and national averages

Default scenarios in BESS model for different regions and biorefinery types

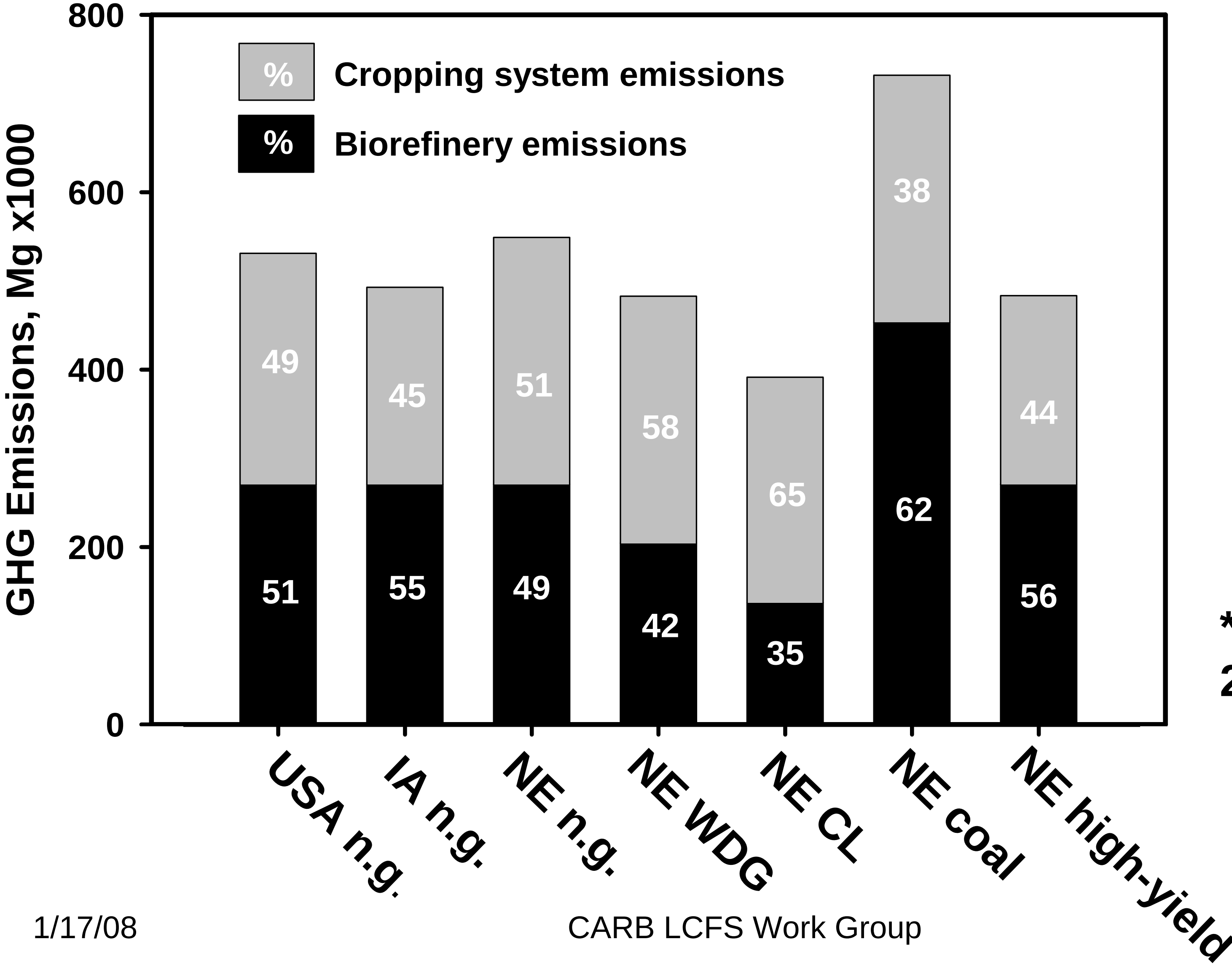
Scenario #	Crop production region	Biorefinery energy (dry mill)	Co-product type
1	USA average	natural gas	dry DGS
2	Iowa average	natural gas	dry DGS
3	Nebraska average	natural gas	dry DGS
4	Nebraska average	natural gas	wet DGS
5	Nebraska average	nat. gas, closed-loop	wet DG
6	Nebraska average	coal	dry DGS
7	High yield progressive	natural gas	dry DGS

Agricultural and biorefinery energy inputs for BESS default simulation scenarios, and output metrics

Scenario #		USA	IA	NE	NE	NE	NE	HYP
Agricultural energy inputs	MJ L^{-1}	**4.70**	**3.62**	**6.07**	**6.07**	**4.81**	**6.07**	**4.59**
Biorefinery types and energy inputs		nat. gas	nat. gas	**nat. gas**	**n. g. WDG**	**closed -loop**	**coal**	nat. gas
Thermal energy	MJ L^{-1}	5.99	5.99	5.99	5.99	3.04	6.15	5.99
Drying co-product	MJ L^{-1}	2.93	2.93	2.93	0	0	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
Total, biorefinery	MJ L^{-1}	**12.06**	**12.06**	**12.06**	**8.94**	**6.61**	**13.18**	**12.06**
Net energy and GHG emissions								
Net Energy Ratio	ratio	1.48	1.55	1.39	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
Ethanol-Petroleum	ratio	11.9	13.2	9.9	10.4	8.8	9.9	19.2
GHG emissions	gCO2e/MJ	**49**	**46**	**50**	**37**	**31**	**73**	**45**
GHG emissions	reduction	**44%**	**48%**	**43%**	**58%**	**65%**	**17%**	**48%**

BESS Model Results, vers. 2008.2.0, www.bess.unl.edu

Greenhouse gas emissions from different corn-ethanol systems, BESS* defaults



*BESS version 2008.2.0

Inventory of GHG emissions from corn-ethanol life-cycle:

IA natural gas biorefinery drying distiller's grains in (BESS default #2)

N2O* = 50% crop GHG emissions, 23% of life-cycle emissions

*includes synthetic N, manure, crop residue, volatilization, leaching/runoff (IPCC 2006)

Component	GHG emission category	% of LC	Mg CO2e*
CROP Production			
	Nitrogen fertilizer, N	6.7	33,109
	Phosphorus fertilizer, P	1.5	7,504
	Potassium fertilizer, K	0.9	4,272
	Lime	4.5	22,238
	Herbicides	2.4	11,897
	Insecticides	0.0	138
	Seed	0.3	1,517
	Gasoline	0.6	2,794
	Diesel	2.8	13,641
	LPG	2.0	9,767
	Natural gas	0.0	0
	Electricity	0.5	2,278
	Depreciable capital	0.4	2,112
	N emissions**-N2O	22.5	110,917
	TOTAL	45.1	**222,184**
BIOREFINERY			
	Natural Gas Input	27.5	135,620
	NG Input: drying DG	13.5	66,339
	Electricity input	9.4	46,395
	Depreciable capital	0.7	3,663
	Grain transportation	3.8	18,484
	TOTAL	54.9	**270,501**
CO-PRODUCT CREDIT			
	Diesel	*0.0*	49
	Urea production	-8.2	-40,353
	Corn production	-17.1	-84,061
	Enteric fermentation-CH4	-2.3	-11,540
	TOTAL	-27.6	**-135,906**
	EBAMM co-product credit	*(-40.4)*	*(-198,975)*
Transportation of ethanol from biorefinery			11,196
LIFE-CYCLE NET EMISSIONS			**367,974**
GHG-intensity of ethanol,	$g\ CO2eq\ MJ^{-1}$	46.0	**367,974**
GHG-intensity of gasoline***,	$g\ CO2eq\ MJ^{-1}$	87.9	701,877
GHG reduction relative to gasoline, %		**47.6%**	333,904

Influence of crop system and biorefinery type on GHG emissions reduction and biofuel carbon intensity (gCO2e MJ^{-1}, %)

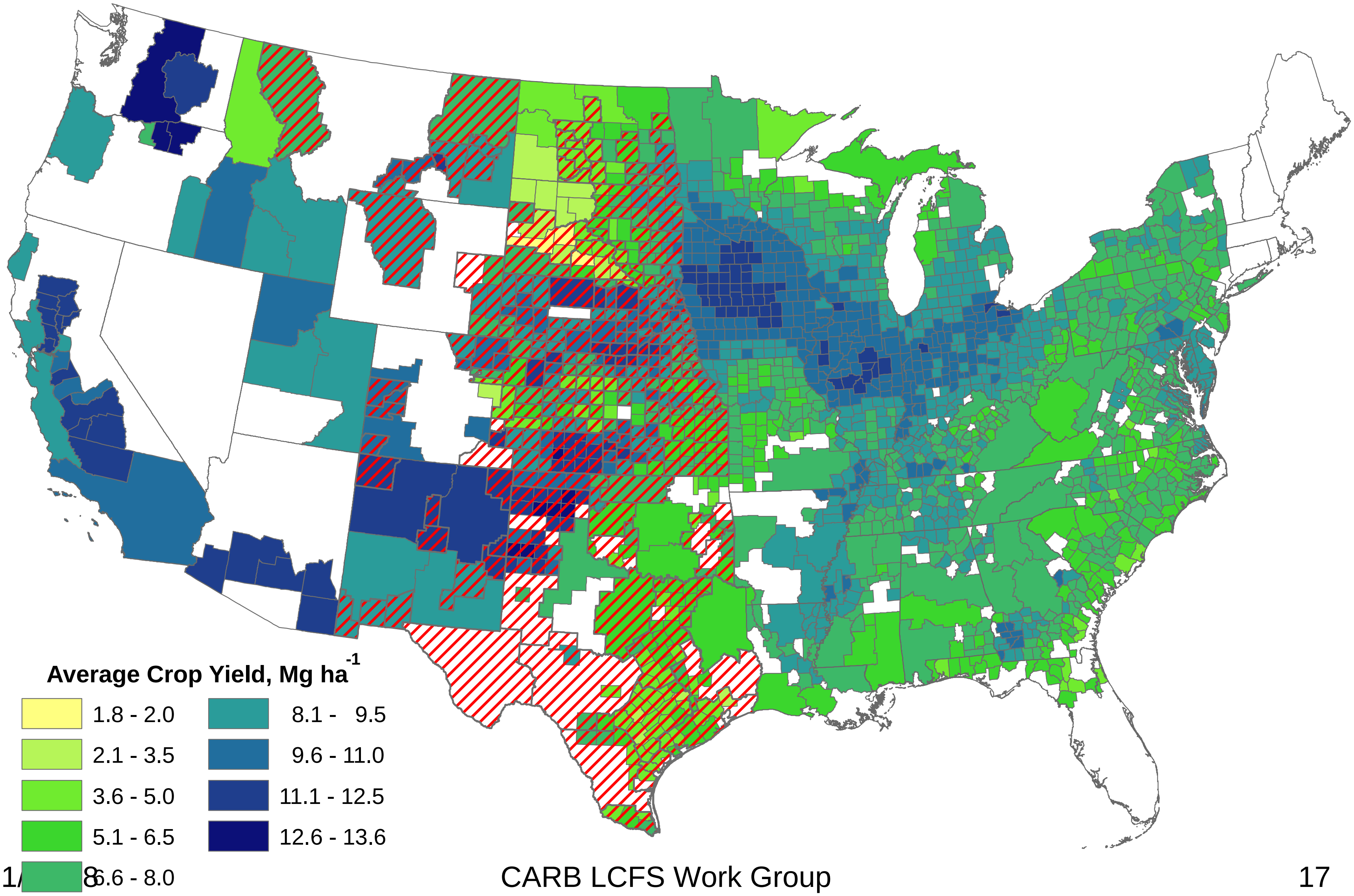
Corn Production System

Biorefinery Type

	USA average	NE average	Iowa average	Advanced Irrigated
coal	18%, 72	17% 73	22%, 69	22% 68
natural gas	44%, 49	43% 50	48% 46	48% 45
natural gas, wet DG	59%, 36	58% 37	62% 33	63% 33
closed-loop facility	67%, 29	65% 31	71% 26	72% 25

BESS Model Results, vers. 2008.2.0, www.bess.unl.edu

<u>USA corn grain yield</u> (2003-2005 average) and irrigation (red hatched, 2001) by county.



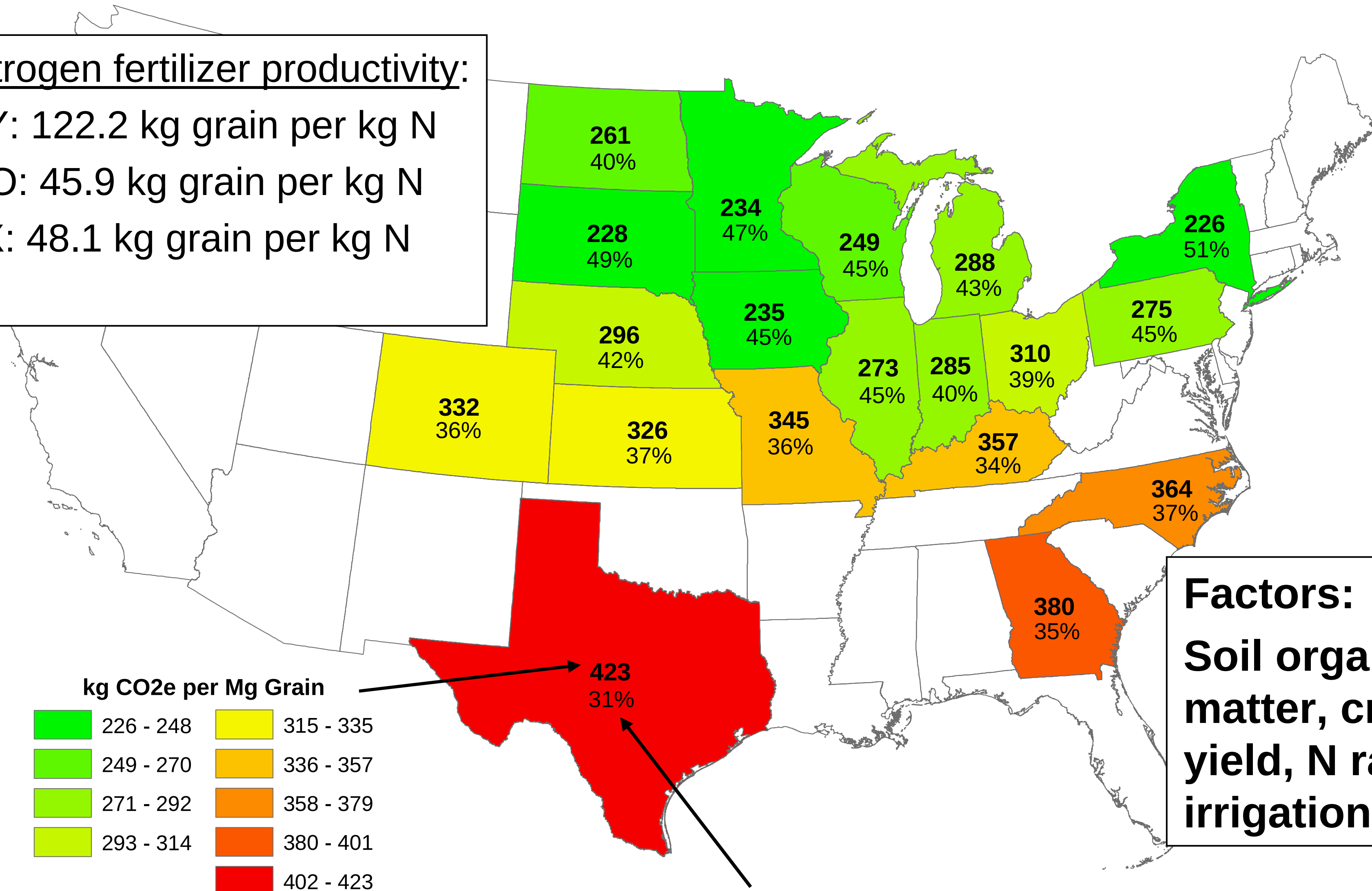
GHG-intensity of corn production (kg CO2eq Mg-1 grain), and life-cycle GHG reductions of corn-ethanol compared to gasoline, assuming natural gas biorefinery with drying distillers grains. (BESS vers. 2008.2.0)

Nitrogen fertilizer productivity:

NY: 122.2 kg grain per kg N

MO: 45.9 kg grain per kg N

TX: 48.1 kg grain per kg N



Factors:

Soil organic matter, crop yield, N rate, irrigation

1/17/08

Life-cycle GHG reduction compared to gasoline: natural gas ethanol plant with dry distillers grains

Conclusions from BESS Analysis

- The GHG-intensity of corn production represents 45-58% of life-cycle GHG emissions for typical USA corn-ethanol systems
- Co-product credits represent 20-40% of life-cycle GHG emissions
  - The BESS model co-product credits are based on current feeding practices and are more realistic than other models; displacement of corn and urea in cattle diets rather than soymeal; BESS co-product credits are more conservative
- Compared to gasoline, typical USA corn-ethanol systems reduce GHG emissions by an average of 43-58%, but the full range is 17-65% due to different *biorefinery designs*, *energy sources*, and *crop production practices*
- Typical USA corn-ethanol systems have net energy ratios ranging 1.4-1.8 depending mostly on biorefinery design and technology, and crop production practices

Other BESS Projects in Progress

- Expansion of BESS model for *cellulosic ethanol* from corn residue and switchgrass (Environmental Defense-funded), will be released in early summer 2008 at www.bess.unl.edu
- Survey of C-intensity and GHG mitigation potential of recently built ethanol plants across the USA Corn Belt
- Analysis of biomass-powered (to replace natural gas) dry-mill ethanol plants in collaboration with University of Minnesota, and ethanol industry
- Manuscripts: (1) description of BESS model and USA ethanol industry analysis, (2) description of co-product credit model

What about land-use change?

- **Major factors affecting land-use change—International**
  - Economic growth rate in populous developing countries (rising incomes, “richer” diets, demand for livestock products/feed grains/oilseeds, urbanization, industrialization)
  - In-country policies and infrastructure development at frontier of rainforests, grassland savannah, and wetlands
  - Currency fluctuations (e.g. US$ vs Brazillian real)
  - Dollar-adjusted commodity prices
- **Major factors affecting land-use change in the USA**
  - Farm Bill conservation titles (CRP, others)
  - Commodity prices
  - Urbanization, industrialization, development (+2M ac/yr))
- **How to estimate direct effects of biofuels independent of the other factors?**
- **Some biofuels have larger direct effects on land-use change (oil palm > soy > corn >sugarcane??)**

Funding Support for BESS Model

- Environmental Defense
- Western Governor's Association
- USDA-CSREES Regional Research
- Nebraska Energy Office
- Nebraska Center for Energy Sciences Research, University of Nebraska-Lincoln, Institute of Agriculture and Natural Resources
- FREE download of BESS model: www.bess.unl.edu

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THANK YOU!

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Comparison of corn-ethanol systems: *Net Energy Ratio* (energy output / input)

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Corn Production System

Biorefinery Type

	USA average	NE average	Iowa average	High-Yield Irrigated
coal	**1.39**	**1.31**	**1.45**	**1.39**
natural gas	**1.48**	**1.39**	**1.55**	**1.48**
natural gas, wet DG	**1.84**	**1.72**	**1.96**	**1.86**
closed-loop facility	**2.40**	**2.13**	**2.65**	**2.42**

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