# Biomass Powered Corn-Ethanol: Influence on Life-Cycle GHG Emissions and BESS Model Methods

University of Nebraska Lincoln

*Profitable Use of Biomass at Ethanol Plants*; Feb. 19-21, 2008

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# *Energy Independence and Security Act of 2007*

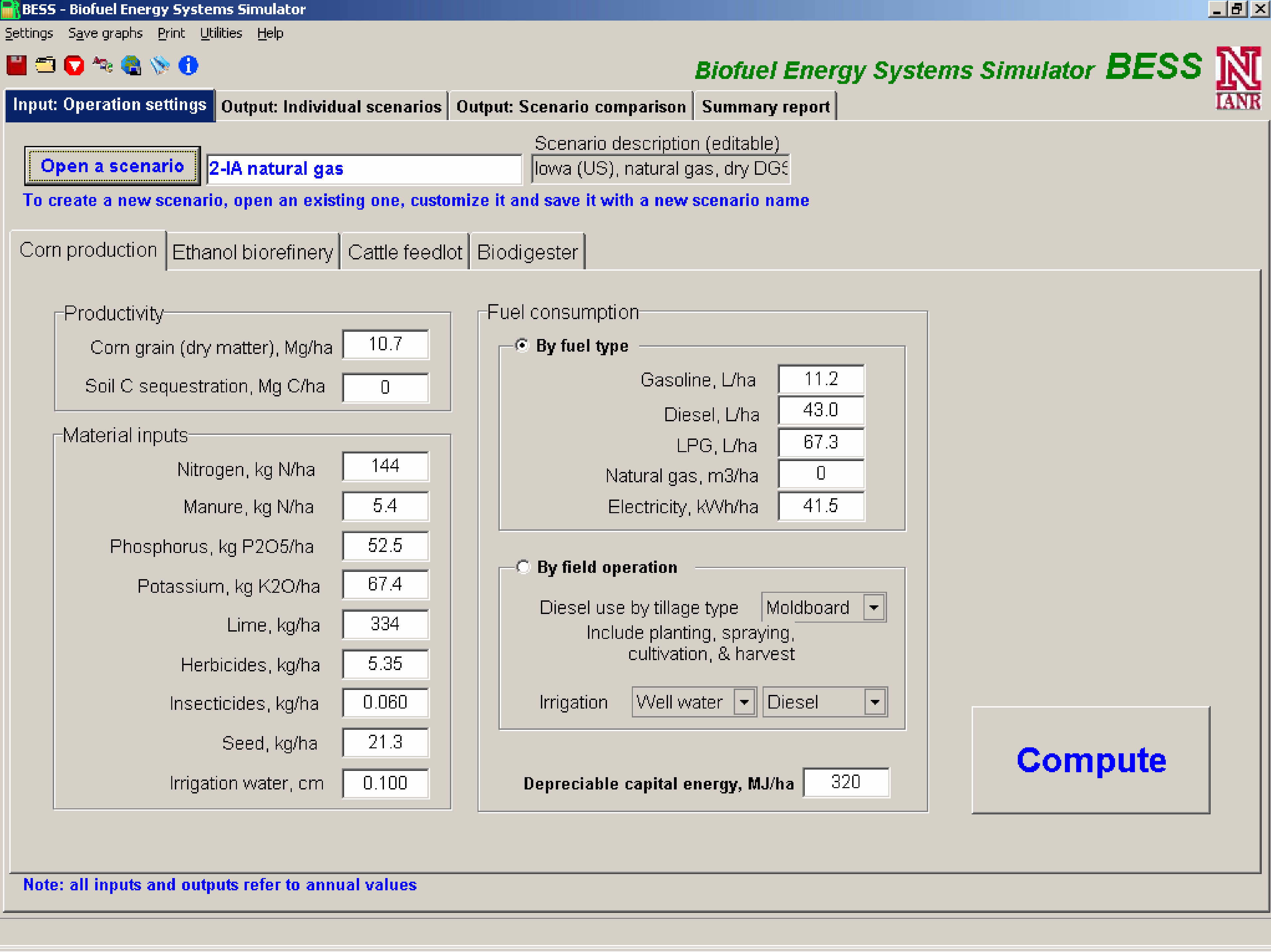
- Renewable Fuel Standard requiring fuel producers to use at least 36 billion gallons of biofuel by 2022, including:
  - <u>15</u> billion gallons as corn-ethanol
  - <u>16</u> billion gallons as cellulosic biofuel
  - <u>5</u> billion gallons as advanced biofuel
- <u>Life-cycle greenhouse gas (GHG) emissions</u> are integral to legislation for regulating biofuel production
- Compared to gasoline,
  - Corn-ethanol must reduce GHG emissions by <u>20%</u>
  - Cellulosic ethanol must reduce GHGs by <u>60%</u>
  - Advanced biofuels must reduce GHGs by <u>50%</u>

# Toward Analyzing Individual Biofuel Systems

- On average, corn-ethanol production has been recently estimated to reduce net GHG emissions by 13% compared to gasoline (Farrell *et al.*, *Science* 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
- EPA's California Air Resources Board is currently standardizing the analysis of life-cycle GHG emissions for biofuels (http://www.arb.ca.gov/fuels/lcfs/lcfs.htm#new)

# Biofuel Energy Systems Simulator (*BESS Model*): Life-Cycle Energy & GHG Emissions of Corn-Ethanol

- Analysis of an *individual* biorefinery & crop production zone
- BESS Model includes 4 components:
  - Crop production
  - Ethanol biorefinery
  - Cattle feedlot for feeding co-product 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 ($CO_2$) and trace greenhouse gases ($CH_4$, $N_2O$), and global warming potential (GWP)
  - **Resource Requirements**—crop production area, grain, water, fossil fuels (petroleum, nat. gas, and coal)



2-IA natural gas

Scenario description (editable): Iowa (US), natural gas, dry DG

**To create a new scenario, open an existing one, customize it and save it with a new scenario name**

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**

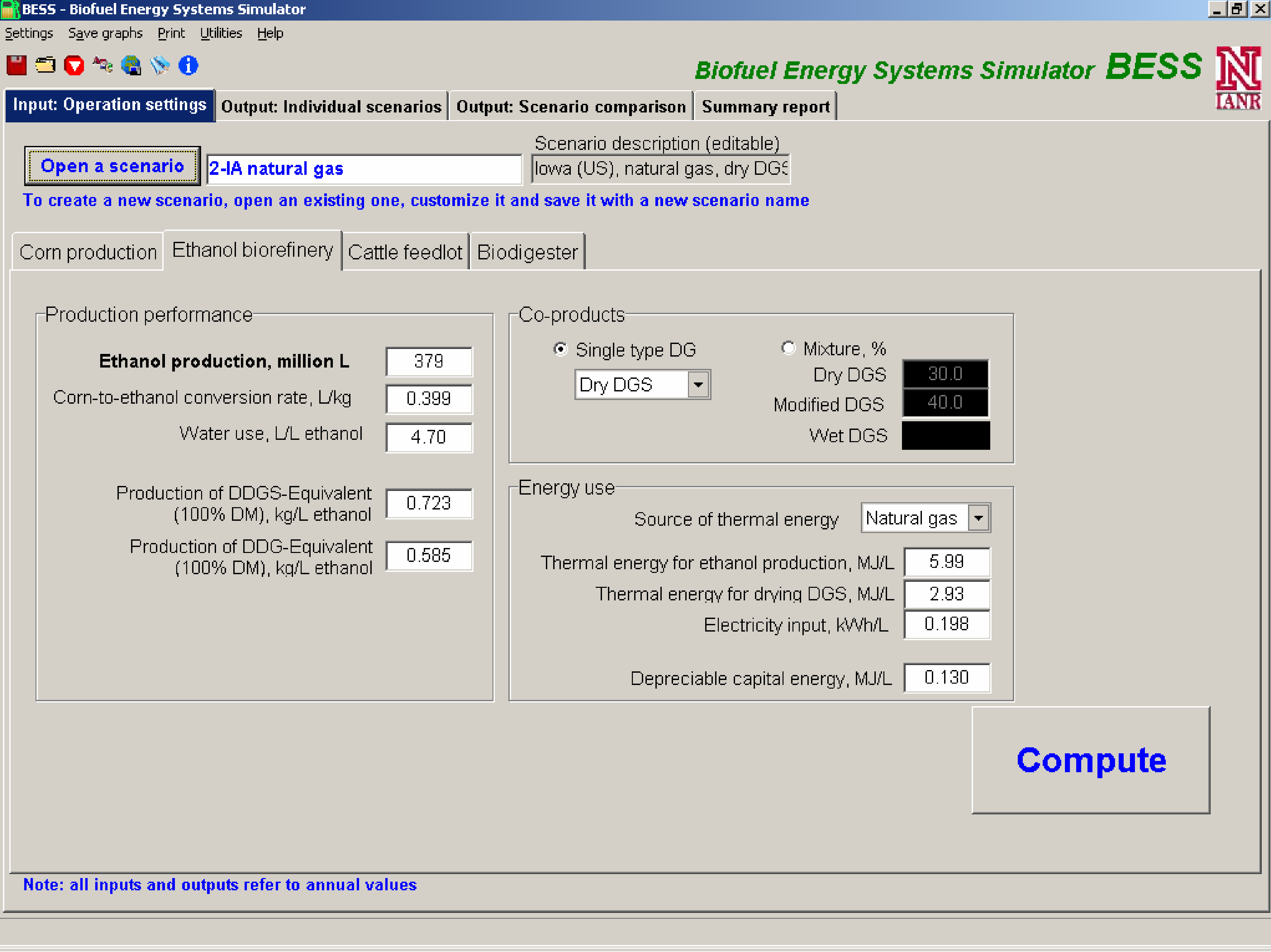
Diesel use by tillage type: Moldboard

Include planting, spraying, cultivation, & harvest

Irrigation: Well water; Diesel

**Depreciable capital energy, MJ/ha** 320

**Note: all inputs and outputs refer to annual values**



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

Production performance

| | |
|---|---|
| **Ethanol production, million L** | 379 |
| Corn-to-ethanol conversion rate, L/kg | 0.399 |
| Water use, L/L ethanol | 4.70 |
| Production of DDGS-Equivalent (100% DM), kg/L ethanol | 0.723 |
| Production of DDG-Equivalent (100% DM), kg/L ethanol | 0.585 |

Co-products

● Single type DG: Dry DGS

○ Mixture, %

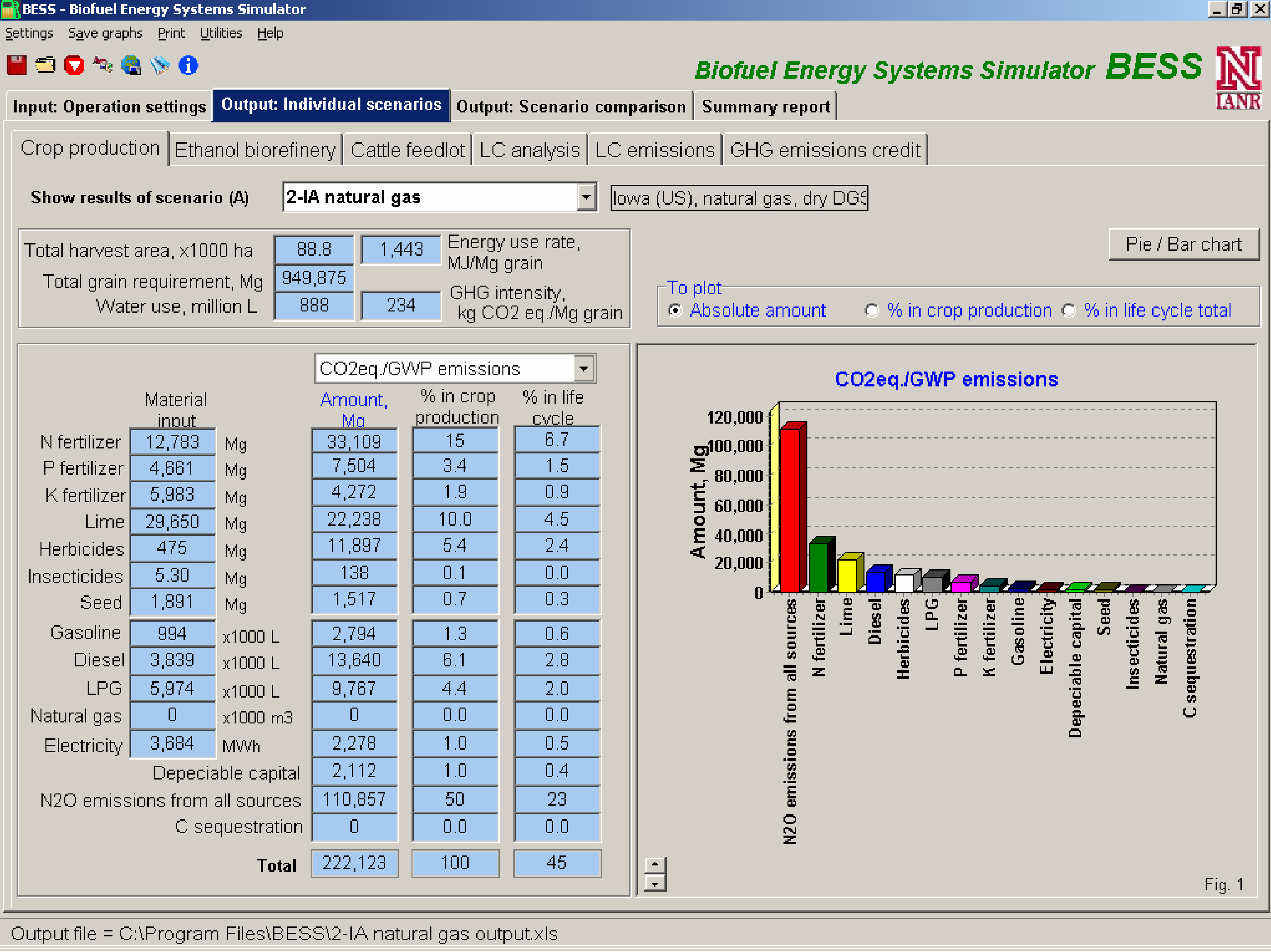
| | |
|---|---|
| Dry DGS | 30.0 |
| Modified DGS | 40.0 |
| Wet DGS | |

Energy use

Source of thermal energy: Natural gas

| | |
|---|---|
| Thermal energy for ethanol production, MJ/L | 5.99 |
| Thermal energy for drying DGS, MJ/L | 2.93 |
| Electricity input, kWh/L | 0.198 |
| Depreciable capital energy, MJ/L | 0.130 |

Note: all inputs and outputs refer to annual values



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

Total harvest area, x1000 ha: 88.8

Total grain requirement, Mg: 949,875

Water use, million L: 888

Energy use rate, MJ/Mg grain: 1,443

GHG intensity, kg CO2 eq./Mg grain: 234

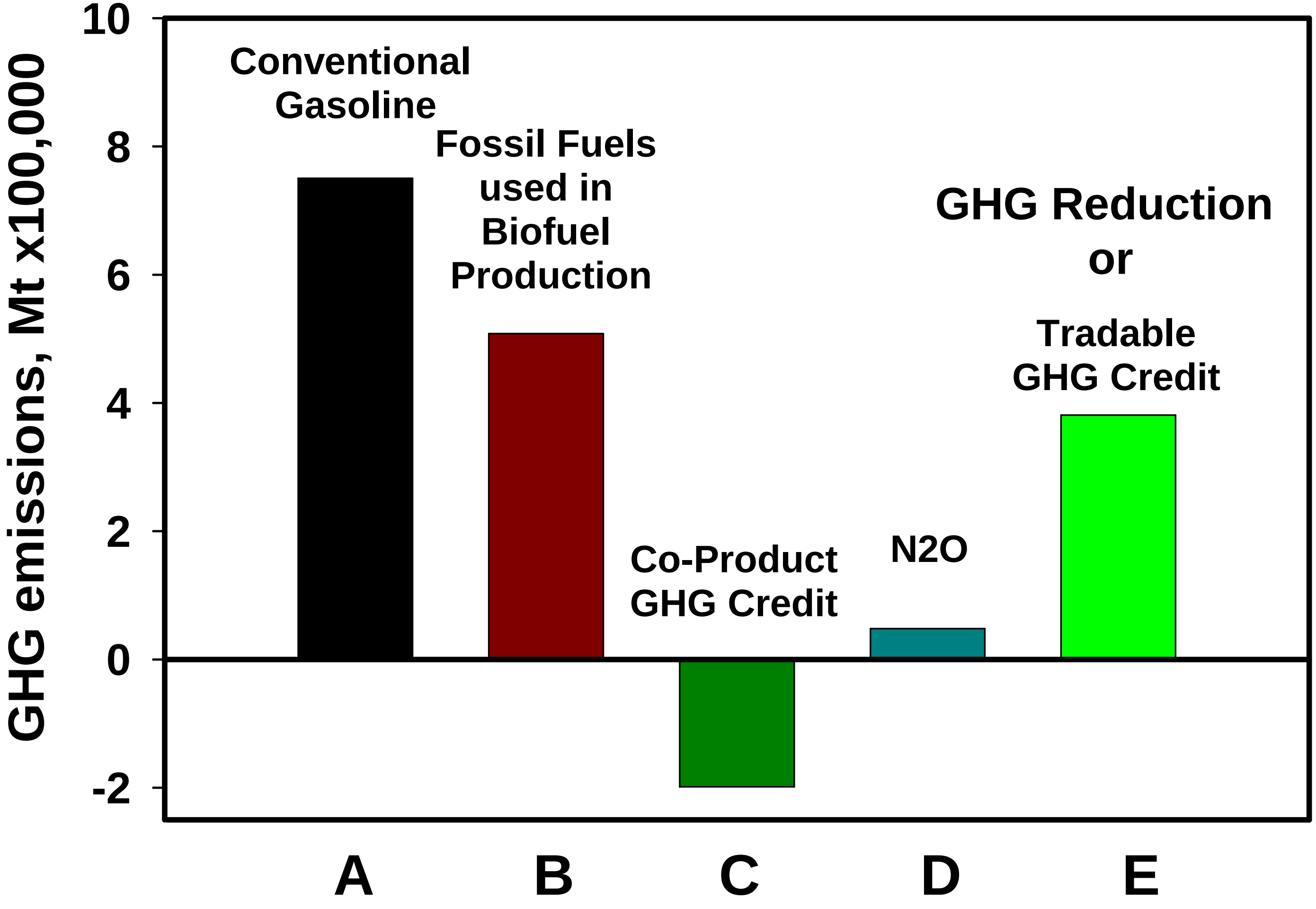
To plot: ● Absolute amount ○ % in crop production ○ % in life cycle total

CO2eq./GWP emissions

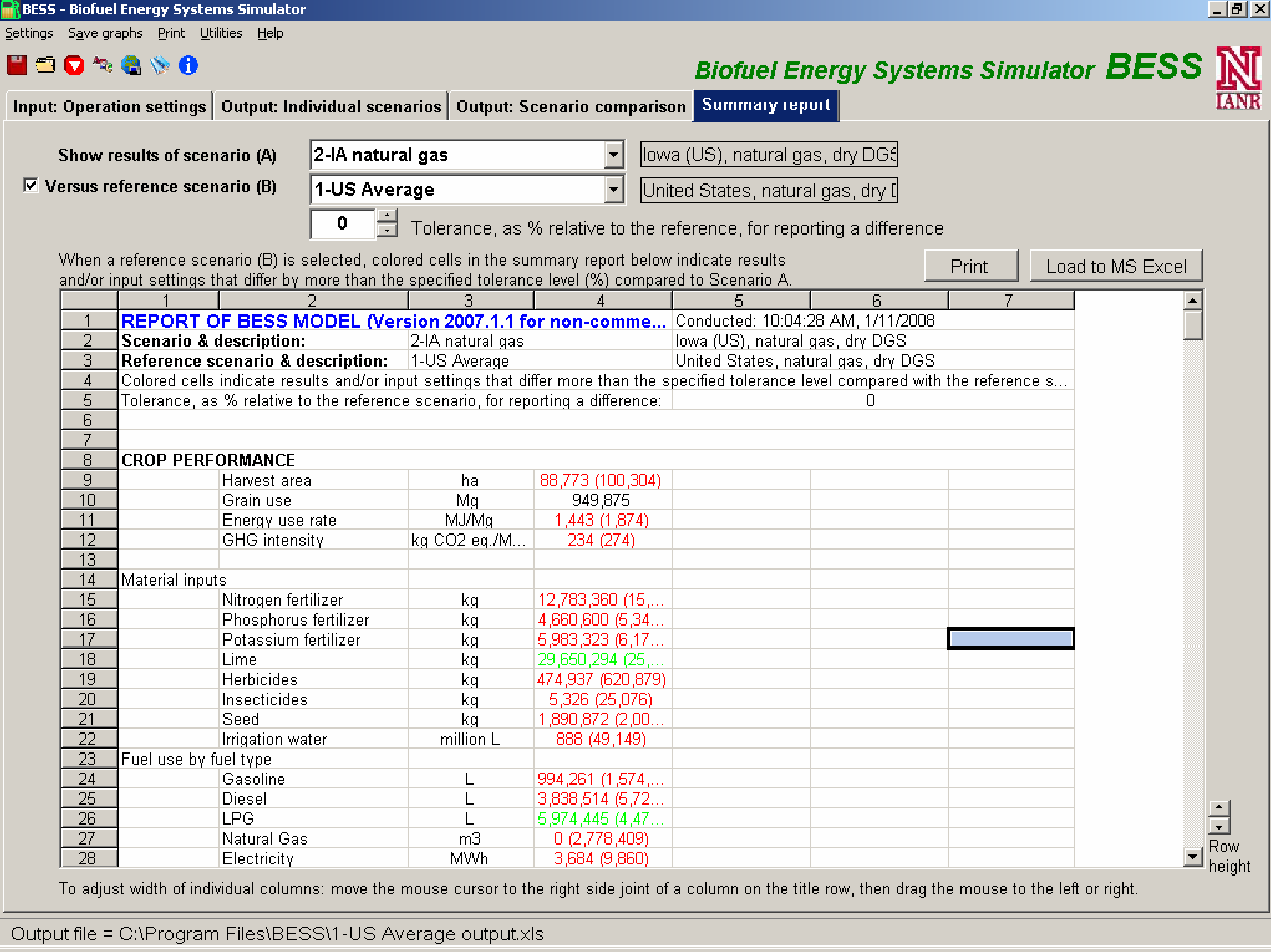
| | Material input | | Amount, Mg | % in crop production | % in life cycle |
|---|---|---|---|---|---|
| N fertilizer | 12,783 | Mg | 33,109 | 15 | 6.7 |
| P fertilizer | 4,661 | Mg | 7,504 | 3.4 | 1.5 |
| K fertilizer | 5,983 | Mg | 4,272 | 1.9 | 0.9 |
| Lime | 29,650 | Mg | 22,238 | 10.0 | 4.5 |
| 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

# GHG emissions reductions due to biofuels (E) = A - B - C - D



**C = co-products displace <u>corn grain</u> and <u>urea</u> in cattle diets provide energy and GHG savings**



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

☑ **Versus reference scenario (B)** 1-US Average — United States, natural gas, dry [

0 Tolerance, as % relative to the reference, for reporting a difference

When a reference scenario (B) is selected, colored cells in the summary report below indicate results and/or input settings that differ by more than the specified tolerance level (%) compared to Scenario A.

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| 1 | **REPORT OF BESS MODEL (Version 2007.1.1 for non-comme...** | | | | Conducted: 10:04:28 AM, 1/11/2008 | | |
| 2 | **Scenario & description:** | | 2-IA natural gas | | Iowa (US), natural gas, dry DGS | | |
| 3 | **Reference scenario & description:** | | 1-US Average | | United States, natural gas, dry DGS | | |
| 4 | Colored cells indicate results and/or input settings that differ more than the specified tolerance level compared with the reference s... | | | | | | |
| 5 | Tolerance, as % relative to the reference scenario, for reporting a difference: | | | | 0 | | |
| 6 | | | | | | | |
| 7 | | | | | | | |
| 8 | **CROP PERFORMANCE** | | | | | | |
| 9 | | Harvest area | ha | 88,773 (100,304) | | | |
| 10 | | Grain use | Mg | 949,875 | | | |
| 11 | | Energy use rate | MJ/Mg | 1,443 (1,874) | | | |
| 12 | | GHG intensity | kg CO2 eq./M... | 234 (274) | | | |
| 13 | | | | | | | |
| 14 | Material inputs | | | | | | |
| 15 | | Nitrogen fertilizer | kg | 12,783,360 (15,... | | | |
| 16 | | Phosphorus fertilizer | kg | 4,660,600 (5,34... | | | |
| 17 | | Potassium fertilizer | kg | 5,983,323 (6,17... | | | |
| 18 | | Lime | kg | 29,650,294 (25,... | | | |
| 19 | | Herbicides | kg | 474,937 (620,879) | | | |
| 20 | | Insecticides | kg | 5,326 (25,076) | | | |
| 21 | | Seed | kg | 1,890,872 (2,00... | | | |
| 22 | | Irrigation water | million L | 888 (49,149) | | | |
| 23 | Fuel use by fuel type | | | | | | |
| 24 | | Gasoline | L | 994,261 (1,574,... | | | |
| 25 | | Diesel | L | 3,838,514 (5,72... | | | |
| 26 | | LPG | L | 5,974,445 (4,47... | | | |
| 27 | | Natural Gas | m3 | 0 (2,778,409) | | | |
| 28 | | Electricity | MWh | 3,684 (9,860) | | | |

To adjust width of individual columns: move the mouse cursor to the right side joint of a column on the title row, then drag the mouse to the left or right.

Output file = C:\Program Files\BESS\1-US Average output.xls

# BESS Model, vers. 2008.2.0 (Jan. 17, 2008)

# 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 simulation scenarios in BESS model for different cropping regions and biorefinery types

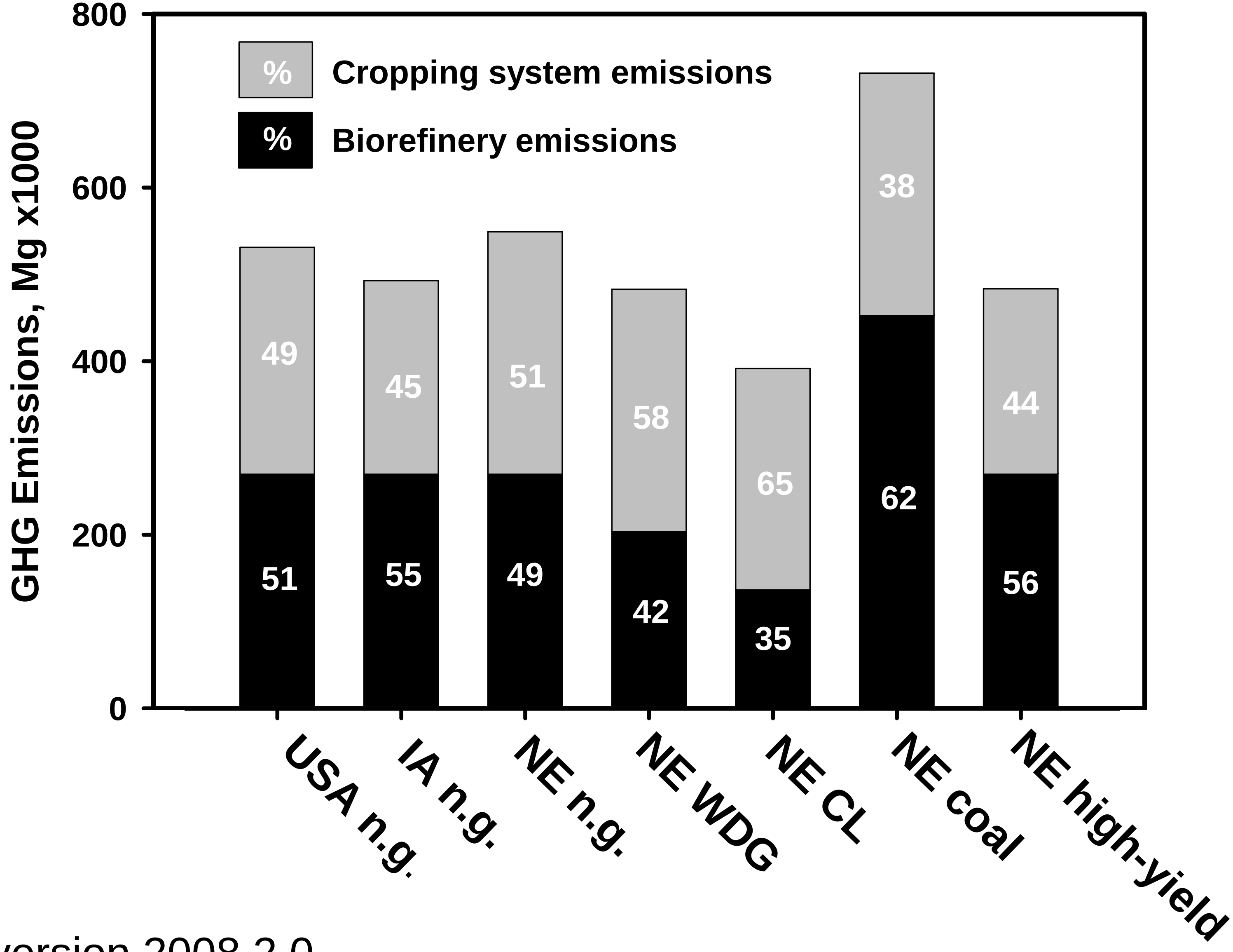
| Scenario # | Crop production region | Biorefinery energy (dry mill) | Co-product type |
|---|---|---|---|
| **1** | USA average | natural gas | dry DGS |
| **2** | Iowa average | natural gas | dry DGS |
| **3** | Nebraska average | natural gas | dry DGS |
| **4** | Nebraska average | natural gas |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

| 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 |

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

# Influence of cropping system and biorefinery type on *Net Energy Ratio* (energy output/input)

**Corn Production System**

**Ethanol Biorefineries**

| | 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 |

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

# Influence of cropping system and biorefinery type on GHG emissions reduction and biofuel carbon intensity: %, Mg CO2e*

*Need to meet 20% reduction*

**Corn Production System**

**Ethanol Biorefineries**

| | USA average | NE average | Iowa average | Advanced Irrigated |
|---|---|---|---|---|
| coal | 18%, 127,000 | 17%, 116,000 | 22%, 151,000 | 22%, 157,000 |
| natural gas | 44%, 310,000 | 43%, 299,000 | **48%, 334,000** | 48%, 340,000 |
| natural gas, wet DG | 59%, 415,000 | **58%, 405,000** | 62%, 436,000 | 63%, 441,000 |
| closed-loop facility | 67%, 473,000 | 65%, 458,000 | 71%, 498,000 | 72%, 504,000 |

***Based on a 100 million gal yr-1 production capacity**

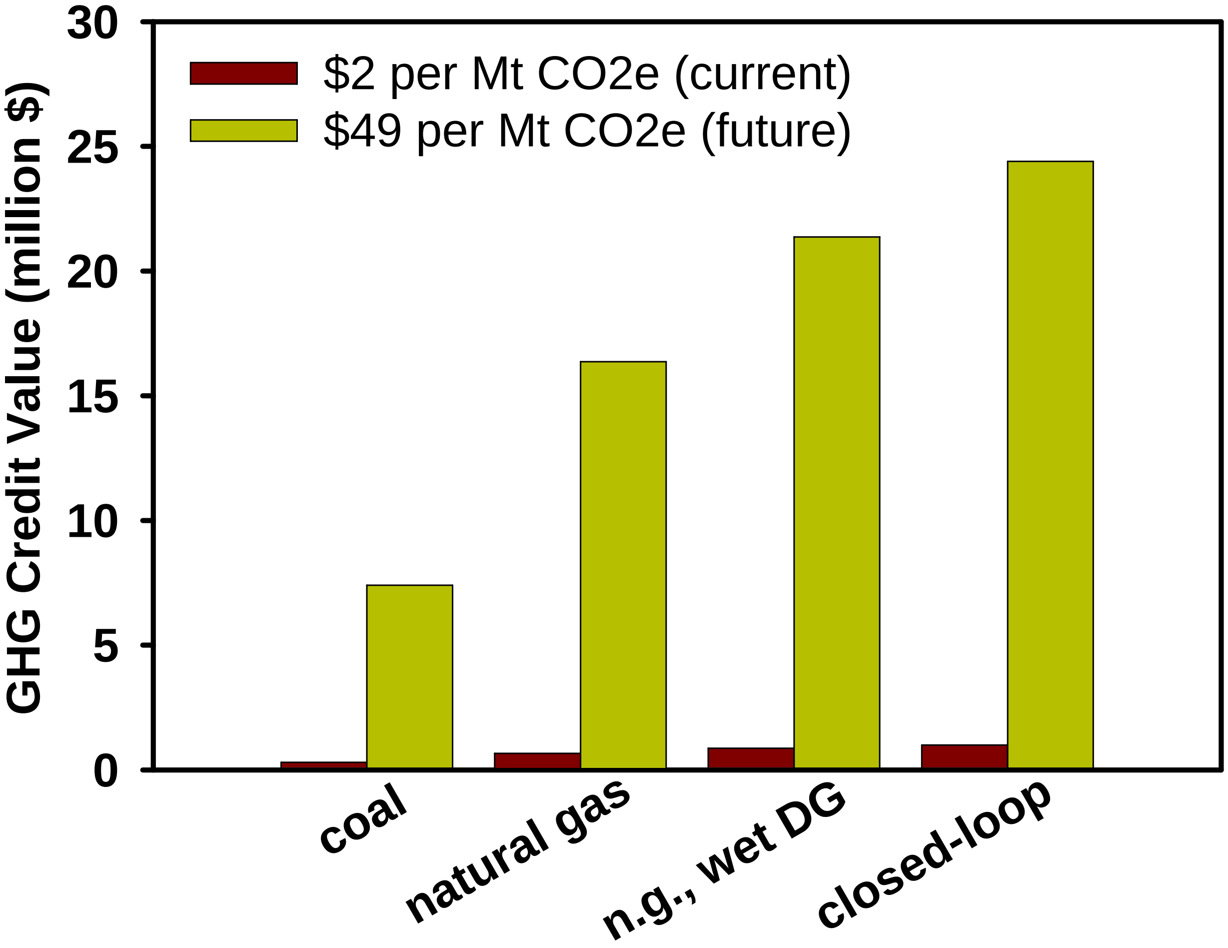
BESS Model Results, vers. 2008.2.0, www.bess.unl.edu

# GHG emissions trading credit (cap-and-trade) for ethanol biorefineries according to type

**Current European price Dec. 16, 2007**

€23 per mt
or
$34 per mt

**At future price**
~$0.2 per gallon



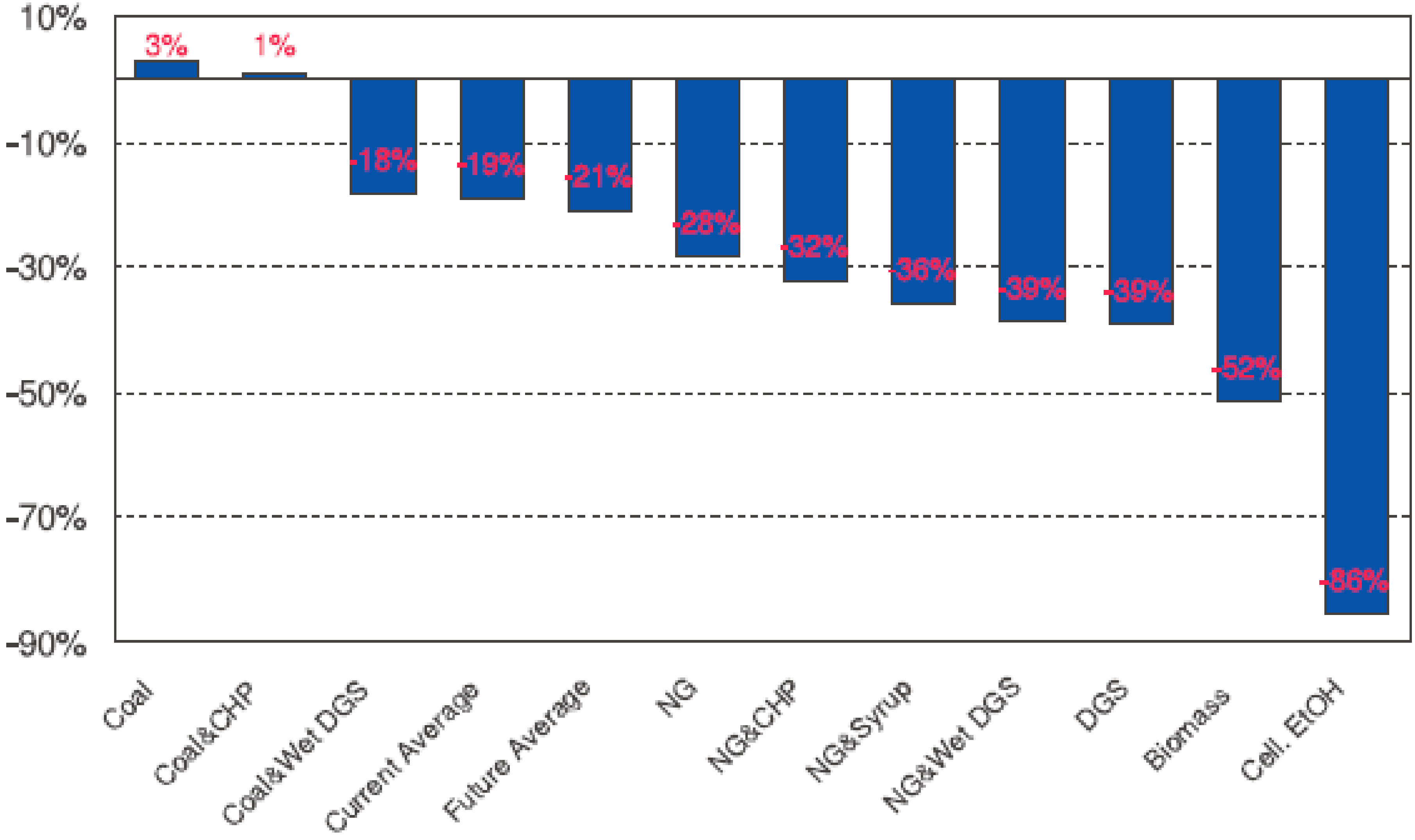
*Based on a 100 million gal yr-1 production capacity in IA; fermentation $CO_2$ not included (neutral); $2 per metric ton CO2e, Dec. 2006, Chicago Climate Exchange; Future carbon price of $49 per metric ton CO2e (Kintisch 2007)
BESS Model Results, vers. 2007.1.1, www.bess.unl.edu

# 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
- 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*
- EPA life-cycle accounting methods are under-development and interested parties should participate in discussions concerning standards

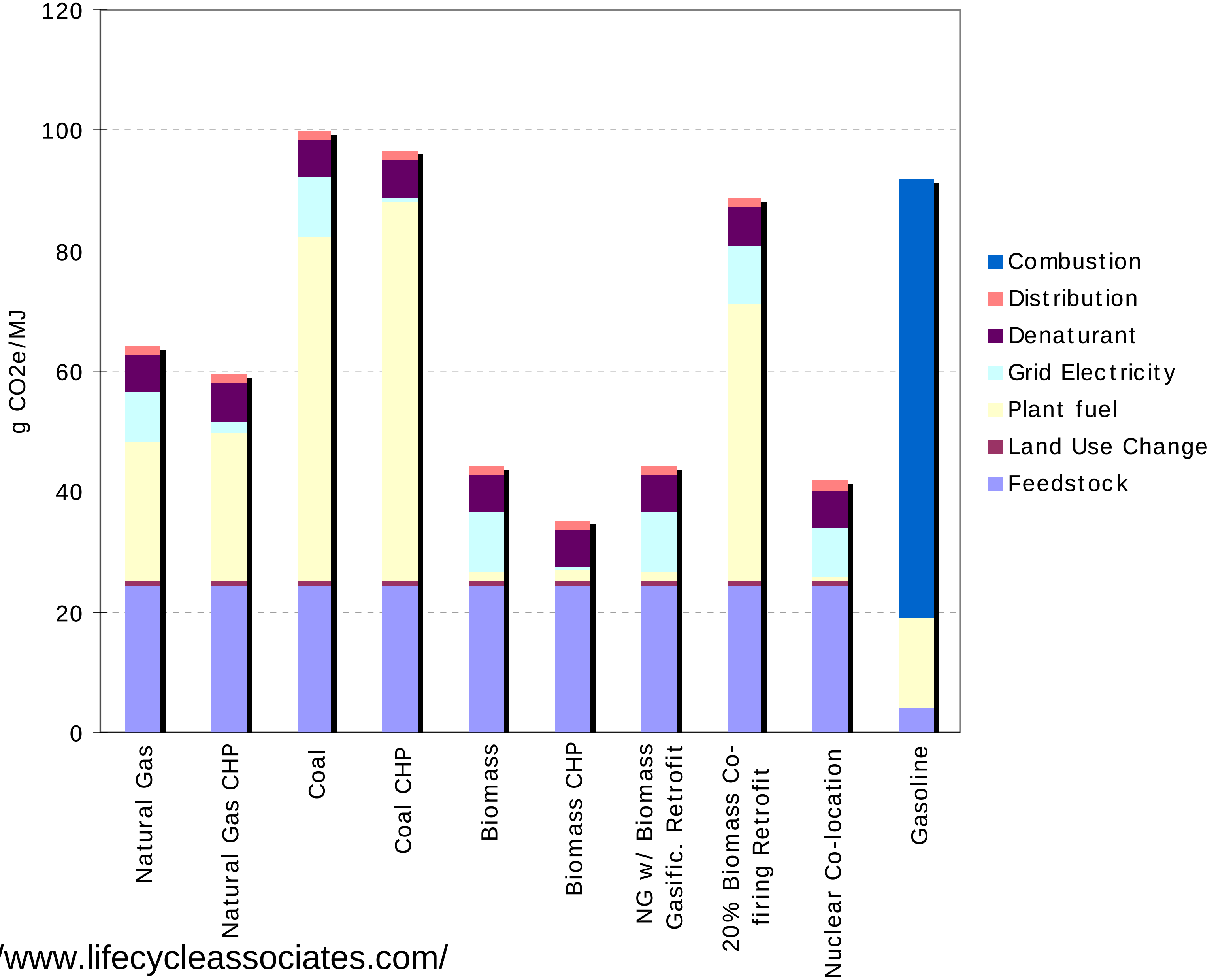
(http://www.arb.ca.gov/fuels/lcfs/lcfs.htm#new)

# **<u>Biomass power:</u>** GHG emissions reductions for corn-ethanol compared to gasoline, using GREET model



Source: Wang M., M. Wu, H. Huo, *Environmental Research Letters* 2, (2007)

# **Biomass power:** GHG intensities of corn-ethanol using the BEACCON model, ver.1.1



Source: http://www.lifecycleassociates.com/

# Unknowns when assessing life-cycle GHG emissions from biomass-powered corn-ethanol

- Changes in soil carbon (net emissions) when removing biomass

  Crop residue removal will significantly reduce soil organic carbon (SOC; Wilhelm 2007). Switchgrass as an energy crop, with heavy removal rates could potentially also not significantly sequester carbon, but would likely be a better source of biomass than residues. Residues are important for maintaining SOC, crop yields, reducing soil erosion, and retaining soil moisture.

  *SOC emissions could be relatively large in life-cycle calculations: 1 Mg C/ha/yr = Δ20% in life-cycle reduction*

- Energy for harvesting and transportation of biomass

  >50% of life-cycle energy inputs into switchgrass cellulosic systems are for harvesting, baling, transportation, and shredding (estimate, *in progress*)

  *Better estimates, models, and accounting is needed*

# Likely changes in GHG budget when using biomass alone to power corn-ethanol dry mills

| | Response* | Life-Cycle GHG Impact |
|---|---|---|
| Biorefinery natural gas use and GHG emissions | down | favorable |
| Diesel for hauling | up | unfavorable |
| Soil carbon emissions | up | unfavorable |

*Compared to natural gas powered corn-ethanol dry mill. Biomass oxidation at the biorefinery produces mostly neutral GHG emissions and reduces life-cycle GHG emissions.

# Likely changes in GHG budget when using biomass and co-products to power corn-ethanol dry mills

| | Response* | Life-Cycle GHG Impact |
|---|---|---|
| Biorefinery natural gas use and GHG emissions | down | favorable |
| Diesel for hauling | up | unfavorable |
| Soil carbon emissions | up | unfavorable |
| Less biomass needed | down | favorable |
| Co-product GHG credit for cattle feeding (*CP credit reduces GHGs by ~25%*) | down | unfavorable |

***compared to natural gas powered corn-ethanol dry mill**

# Conclusions: Biomass power for corn-ethanol

- Previous studies shown significant reductions in life-cycle GHG emissions compared to gasoline and other corn-ethanol systems, but a rigorous assessment is needed on defined biomass systems
- Removal of crop residue is problematic for soil fertility and maintenance of crop yields
- $CO_2$ emissions from SOC changes could be relatively large in life-cycle calculations
- Energy use and associated GHG emissions for harvesting/transportation/storage of biomass could be large
- Energy crops (e.g. switchgrass) for biomass could reduce transportation costs and better maintain soil quality
- Life-cycle assessments need full disclosure of the emissions inventory in a GHG budget, with supporting data used

# Funding Support for BESS Development

- 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

## Acknowledgements

Dan Kenney, and Patrick Tracy, PRIME Biosolutions

- **FREE download of BESS model: www.bess.unl.edu**
- BESS model for CELLULOSIC ETHANOL for Corn residue and switchgrass, *Summer 2008*

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