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

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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 <u>individual ethanol facilities</u> 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

<u>BESS Life-Cycle Model includes 4 components:</u>

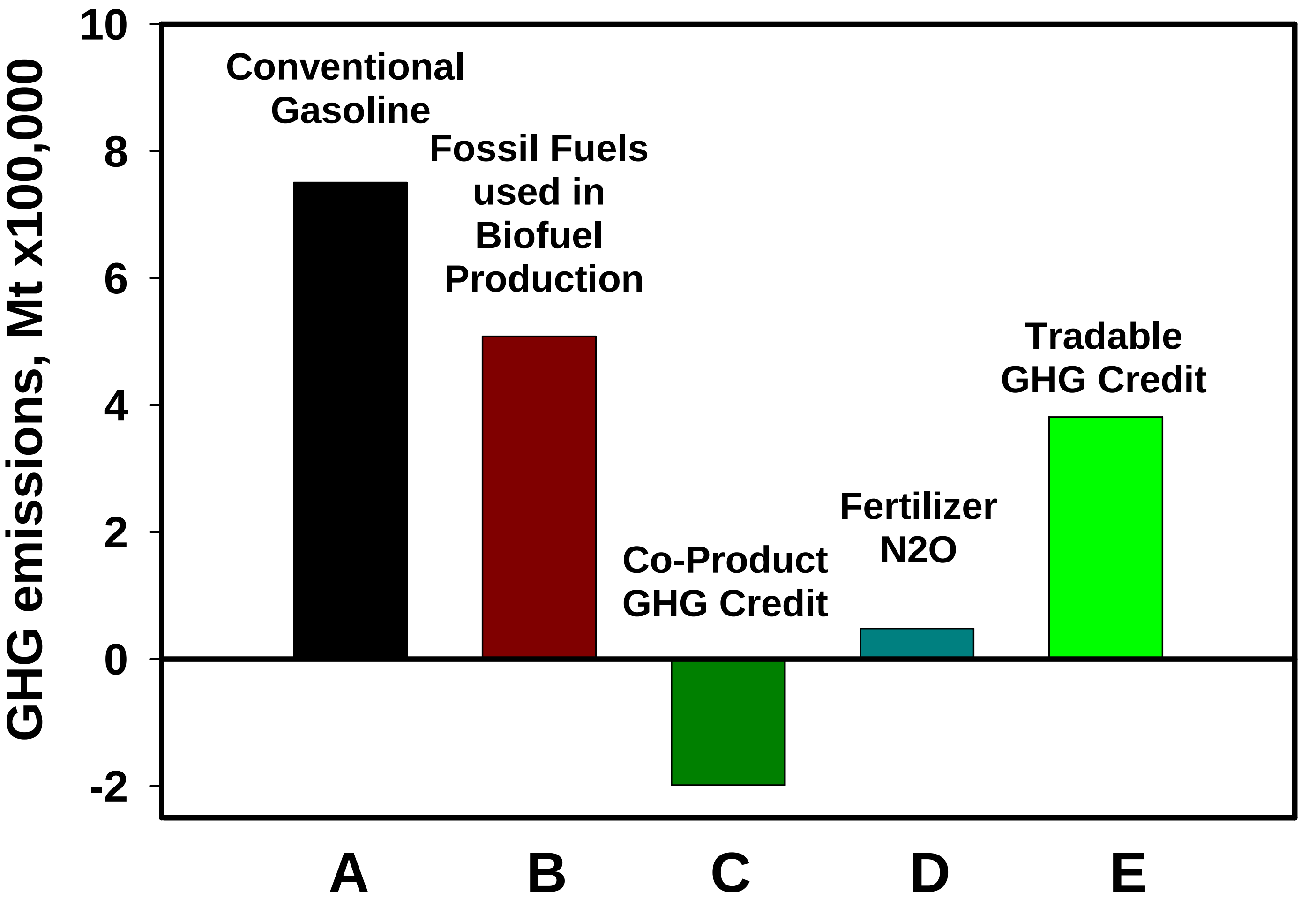
- Crop production
- Ethanol biorefinery
- Cattle feedlot for feeding distiller's grains
- Anaerobic digestion unit (optional, closed-loop facility)

<u>Three types of life-cycle analysis:</u>

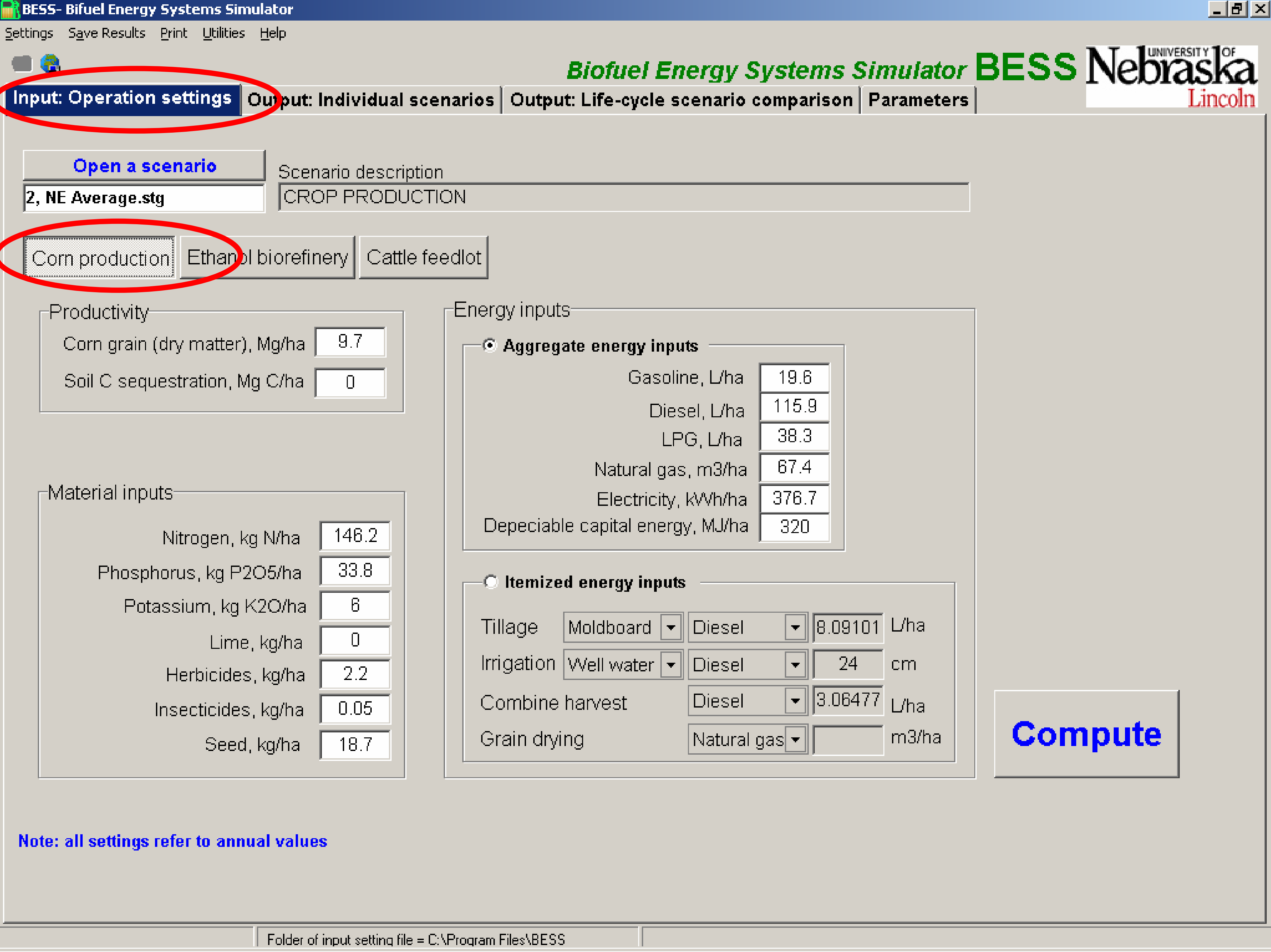
- **Energy analysis**—life-cycle net energy yield/efficiency
- **Emissions analysis**—net carbon dioxide (CO_2) and trace greenhouse gases (CH_4, N_2O), and global warming potentional (GWP)
- **Resource Requirements**—crop production area, grain, water, fossil fuels (petroleum, nat. gas, and coal)

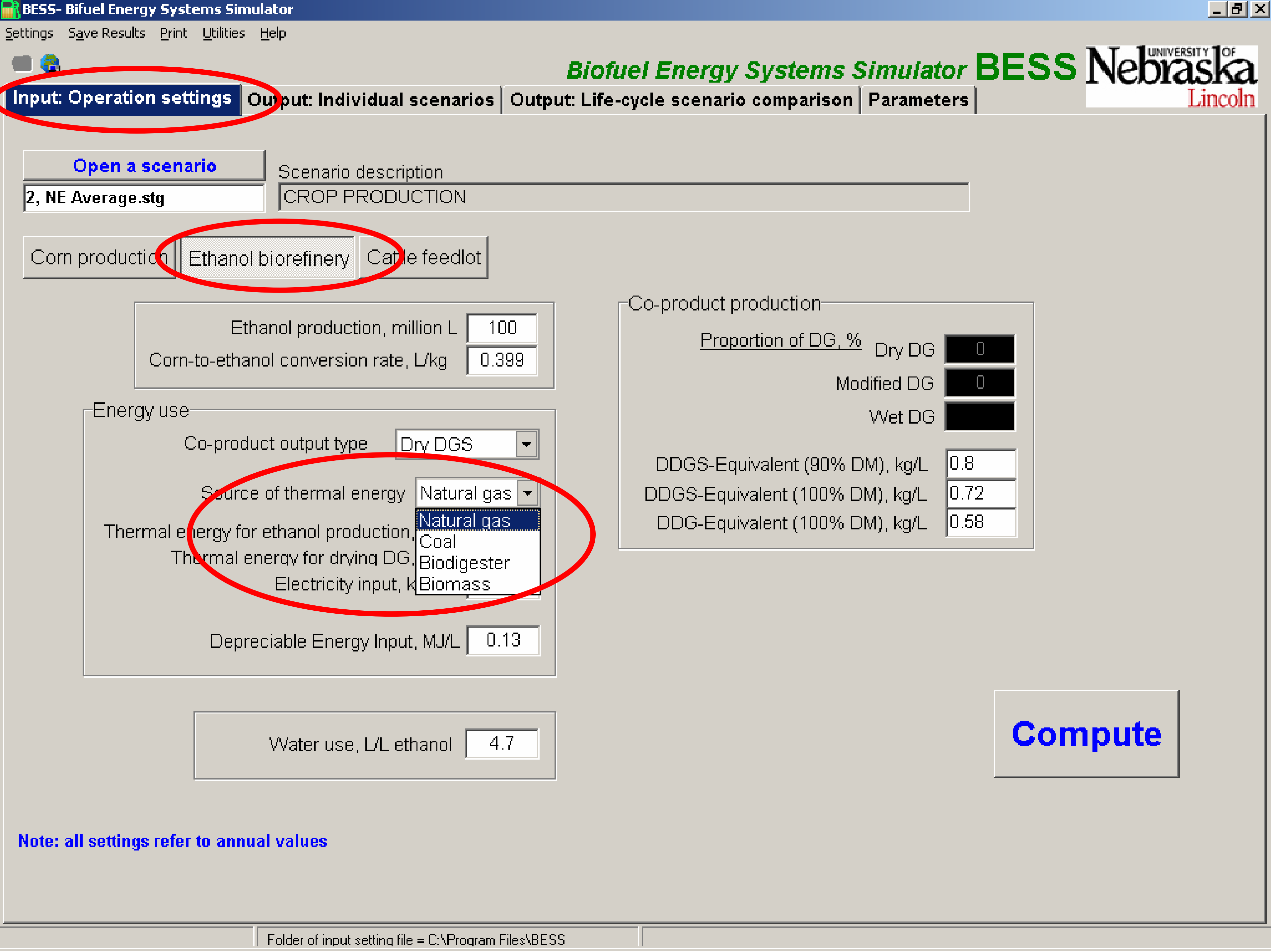
***Funding for BESS development from the Western Governor's Assoc.**

Tradable GHG Credit (E) = A - B - C - D



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


BESS- Bifuel Energy Systems Simulator
Settings Save Results Print Utilities Help
Biofuel Energy Systems Simulator BESS
UNIVERSITY OF Nebraska Lincoln
Input: Operation settings
Output: Individual scenarios
Output: Life-cycle scenario comparison
Parameters
Open a scenario
2, NE Average.stg
Scenario description
CROP PRODUCTION
Corn production
Ethanol biorefinery
Cattle feedlot
Productivity
Corn grain (dry matter), Mg/ha 9.7
Soil C sequestration, Mg C/ha 0
Material inputs
Nitrogen, kg N/ha 146.2
Phosphorus, kg P2O5/ha 33.8
Potassium, kg K2O/ha 6
Lime, kg/ha 0
Herbicides, kg/ha 2.2
Insecticides, kg/ha 0.05
Seed, kg/ha 18.7
Energy inputs
Aggregate energy inputs
Gasoline, L/ha 19.6
Diesel, L/ha 115.9
LPG, L/ha 38.3
Natural gas, m3/ha 67.4
Electricity, kWh/ha 376.7
Depeciable capital energy, MJ/ha 320
Itemized energy inputs
Tillage Moldboard Diesel 8.09101 L/ha
Irrigation Well water Diesel 24 cm
Combine harvest Diesel 3.06477 L/ha
Grain drying Natural gas m3/ha
Compute
Note: all settings refer to annual values
Folder of input setting file = C:\Program Files\BESS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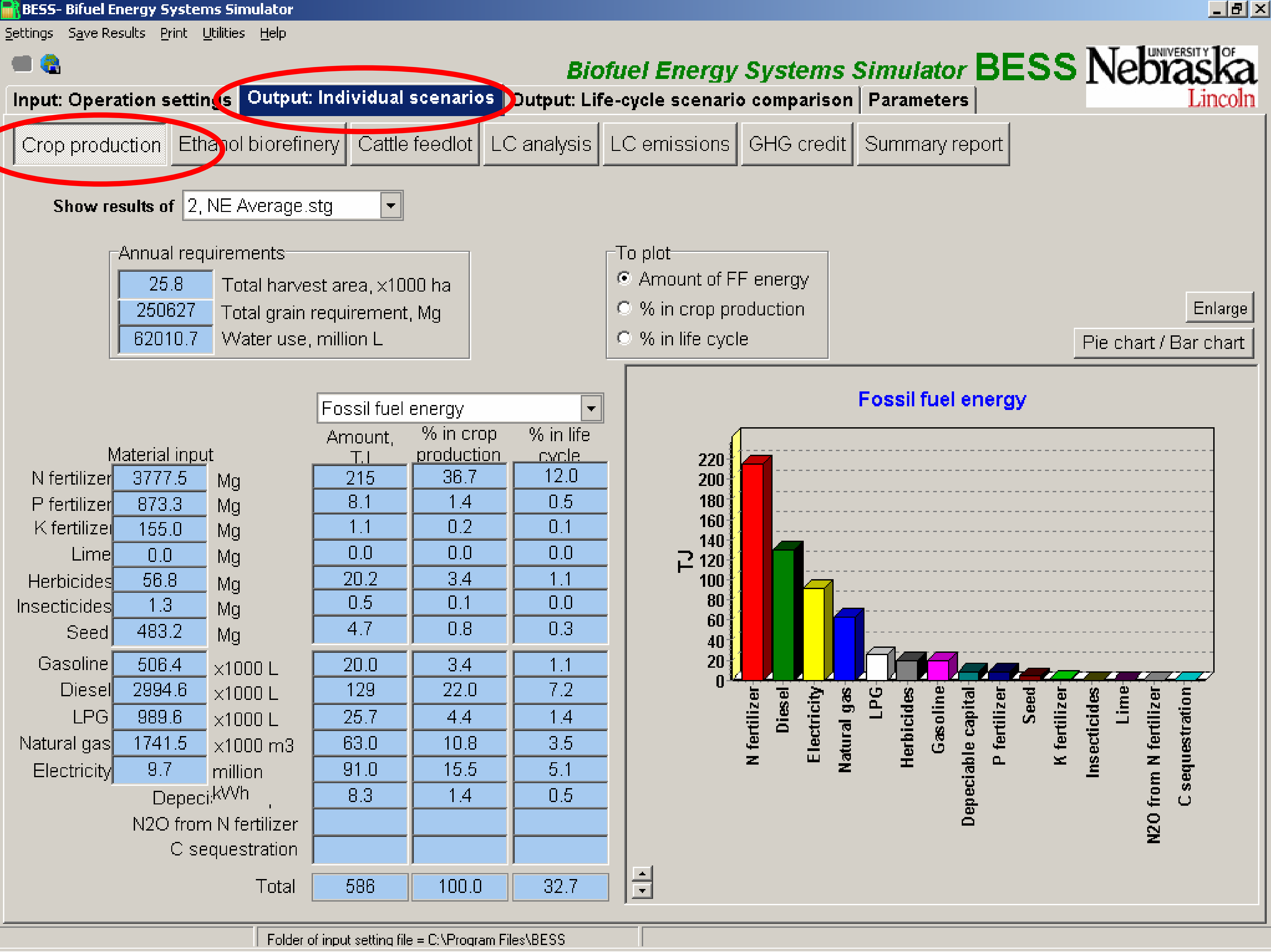
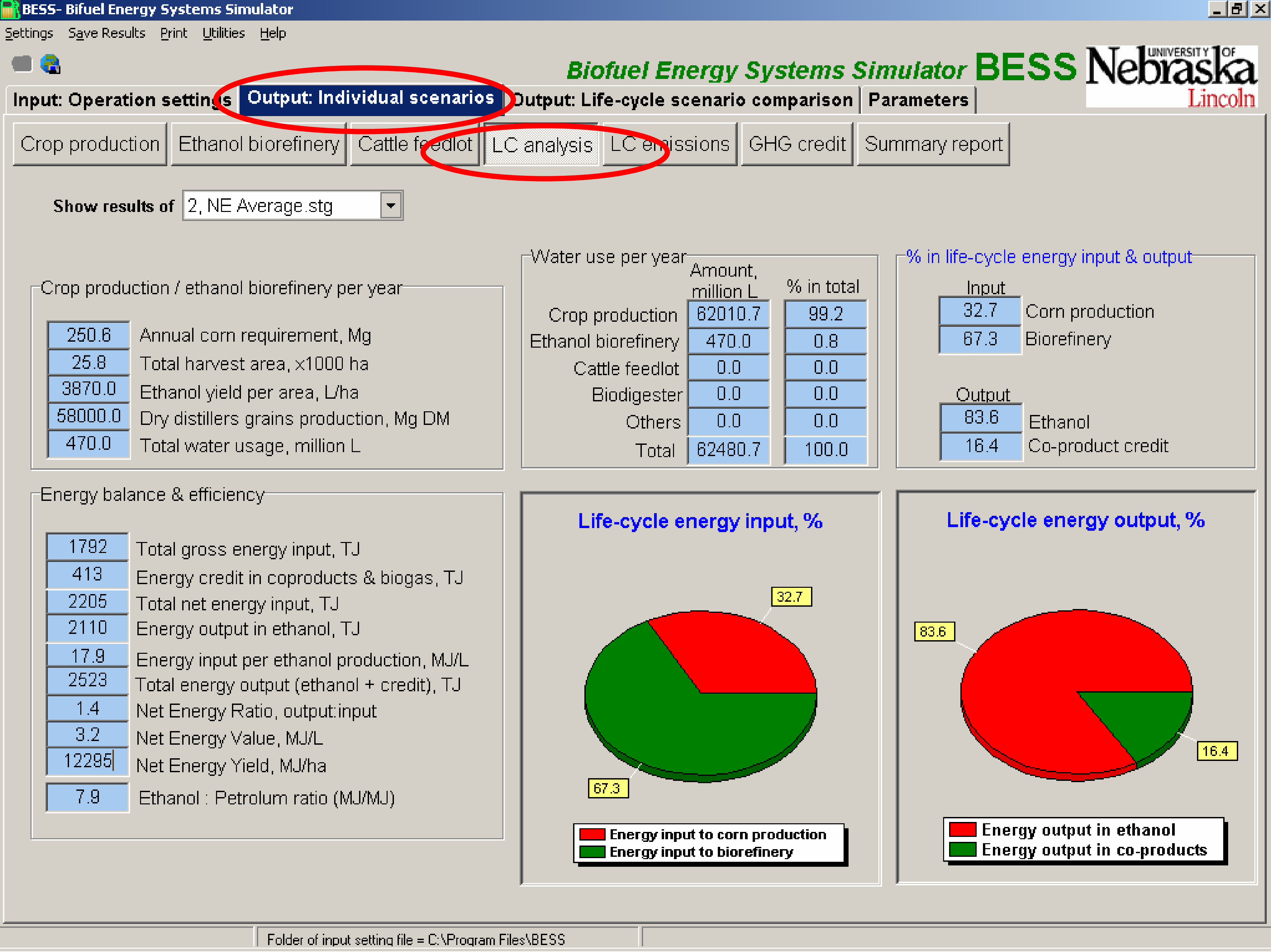
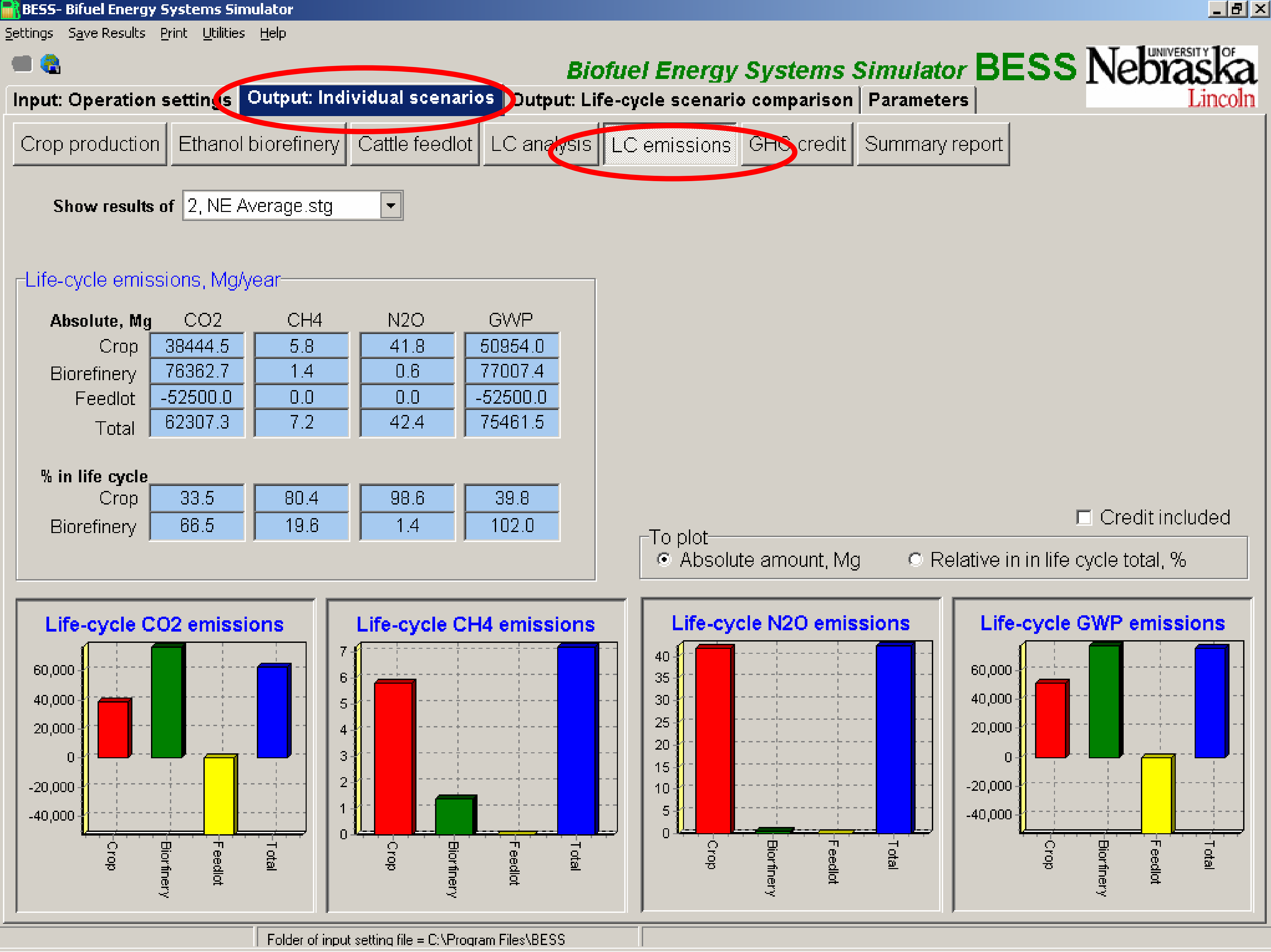
Output: Life-cycle scenario comparison
Parameters
Open a scenario
2, NE Average.stg
Scenario description
CROP PRODUCTION
Corn production
Ethanol biorefinery
Cattle feedlot
Ethanol production, million L
100
Corn-to-ethanol conversion rate, L/kg
0.399
Energy use
Co-product output type
Dry DGS
Source of thermal energy
Natural gas
Thermal energy for ethanol production,
Natural gas
Coal
Thermal energy for drying DG,
Biodigester
Electricity input, k
Biomass
Depreciable Energy Input, MJ/L
0.13
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
Water use, L/L ethanol
4.7
Compute
Note: all settings refer to annual values
Folder of input setting file = C:\Program Files\BESS



BESS- Bifuel Energy Systems Simulator
Settings Save Results Print Utilities Help
Biofuel Energy Systems Simulator BESS
UNIVERSITY OF Nebraska Lincoln
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, TJ
% 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
Depeci 8.3 1.4 0.5
N2O from N fertilizer
C sequestration
Total 586 100.0 32.7
Fossil fuel energy
TJ
220
200
180
160
140
120
100
80
60
40
20
0
N fertilizer
Diesel
Electricity
Natural gas
LPG
Herbicides
Gasoline
Depeciable capital
P fertilizer
Seed
K fertilizer
Insecticides
Lime
N2O from N fertilizer
C sequestration
Folder of input setting file = C:\Program Files\BESS


BESS- Bifuel Energy Systems Simulator
Settings
Save Results
Print
Utilities
Help
Biofuel Energy Systems Simulator BESS
UNIVERSITY OF Nebraska Lincoln
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 : Petrolum ratio (MJ/MJ)
Life-cycle energy input, %
32.7
67.3
Energy input to corn production
Energy input to biorefinery
Life-cycle energy output, %
83.6
16.4
Energy output in ethanol
Energy output in co-products
Folder of input setting file = C:\Program Files\BESS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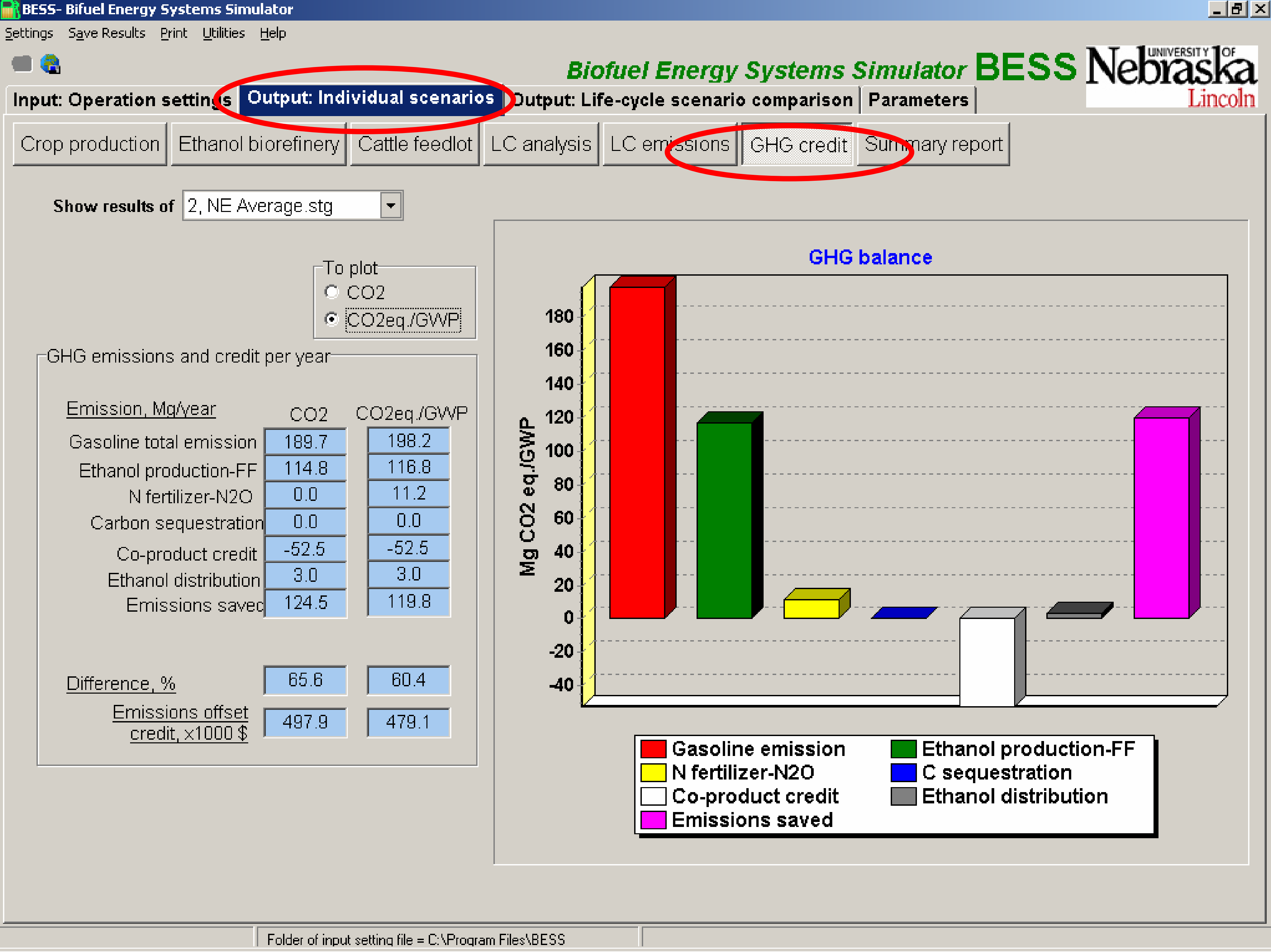
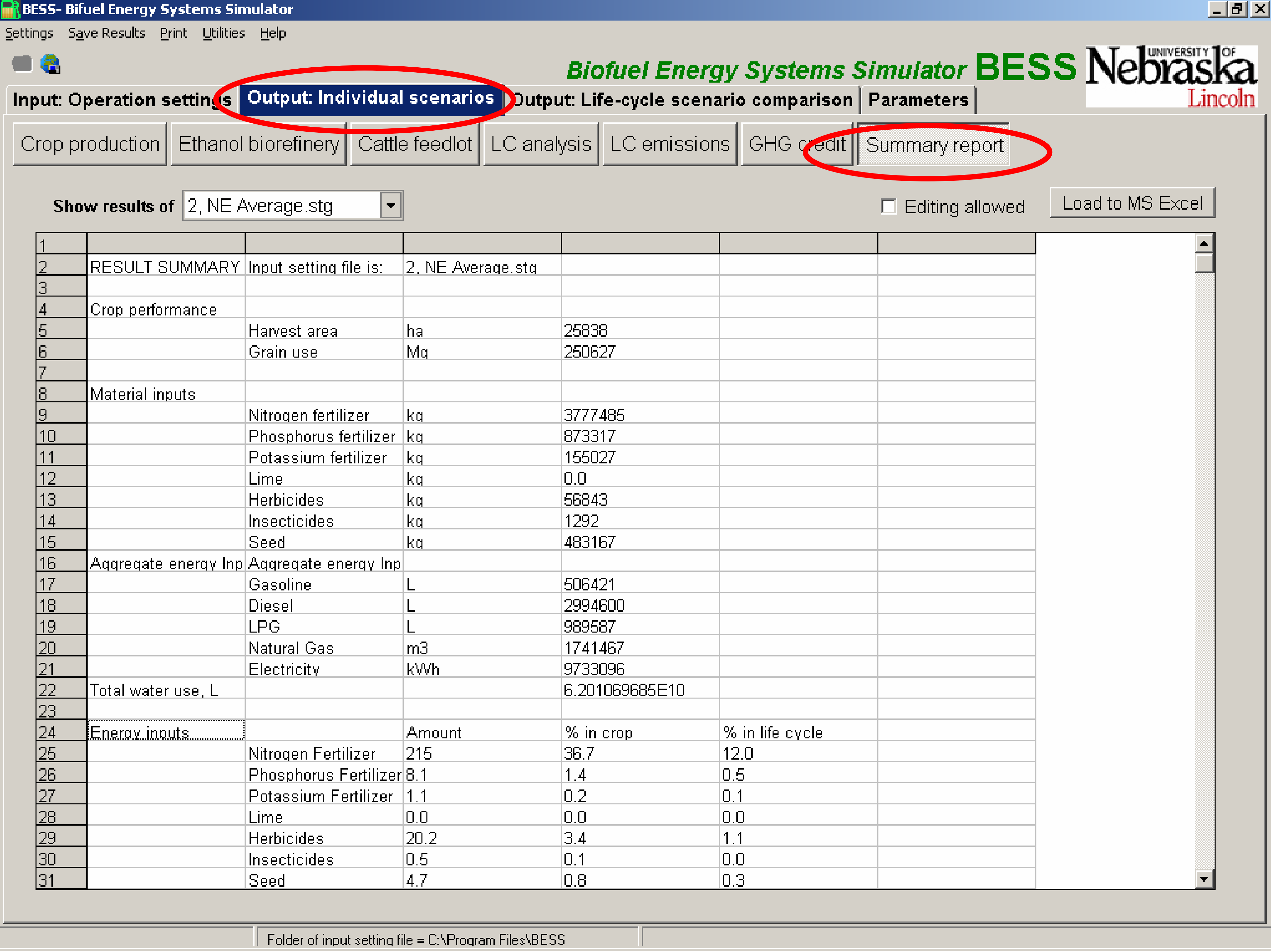
UNIVERSITY OF Nebraska Lincoln
Input: Operation settings
Output: Individual scenarios
Output: Life-cycle scenario comparison
Parameters
Crop production
Ethanol biorefinery
Cattle feedlot
LC analysis
LC emissions
GHG credit
Summary report
Show results of
2, NE Average.stg
Life-cycle emissions, Mg/year
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
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
Crop
Biorfinery
Feedlot
Total
Folder of input setting file = C:\Program Files\BESS


BESS- Bifuel Energy Systems Simulator
Settings Save Results Print Utilities Help
Biofuel Energy Systems Simulator BESS
UNIVERSITY OF Nebraska Lincoln
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
GHG balance
Mg CO2 eq./GWP
180
160
140
120
100
80
60
40
20
0
-20
-40
Gasoline emission
Ethanol production-FF
N fertilizer-N2O
C sequestration
Co-product credit
Ethanol distribution
Emissions saved
Folder of input setting file = C:\Program Files\BESS



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

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

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_2eq*)

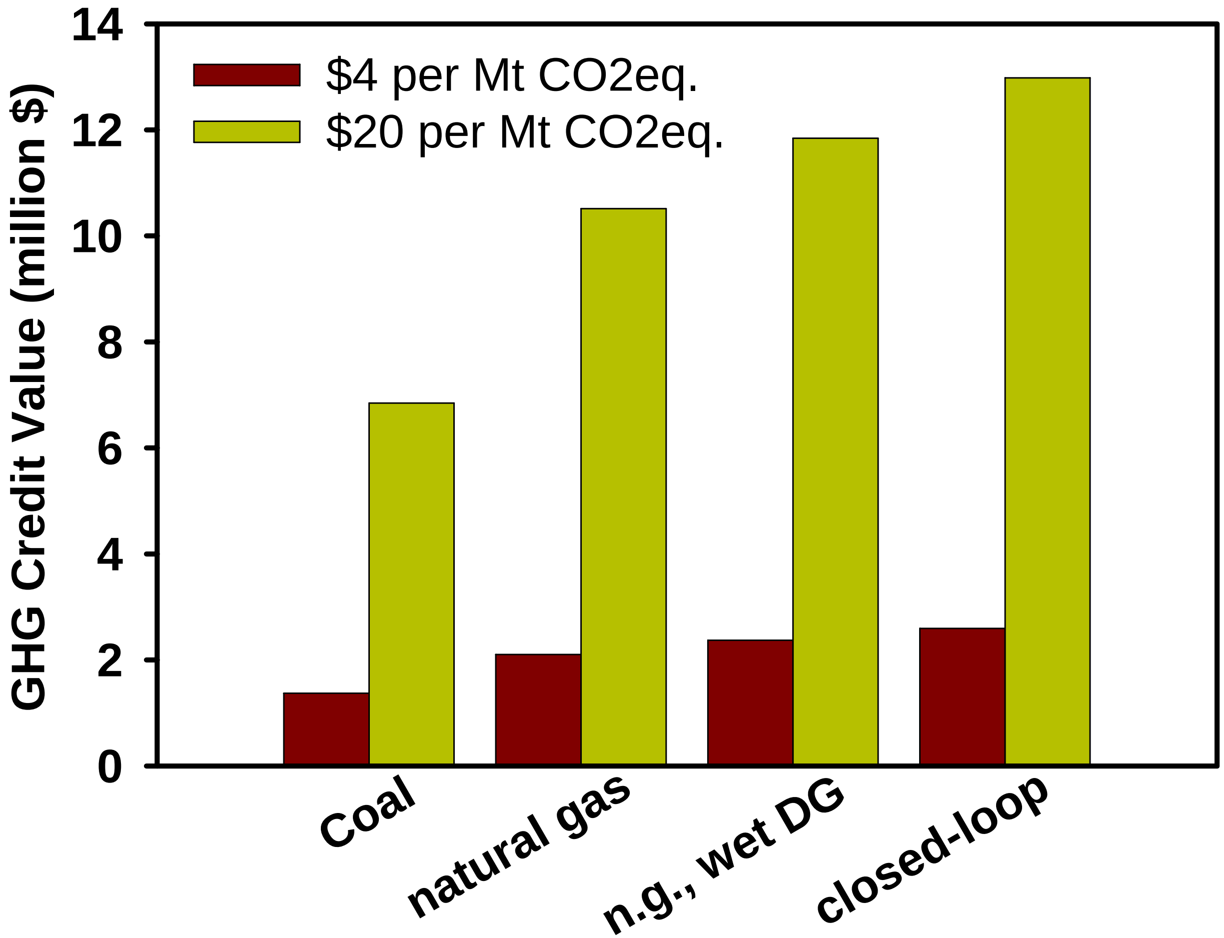
Corn Production System

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-1 production capacity**

GHG Emissions Trading Credit ($)



*Based on a 100 million gal yr-1 production capacity in IA; fermentation CO_2 not included (neutral); $4 per metric ton CO_2, 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 20th, 2007
Software will be freely available from the BESS website:

www.bess.unl.edu

Related References

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