Supplementary Materials

Table S1. Unit operations and energy source of the preprocessing depot.

Unit processes	Unit number	Energy consumption	Energy source
Loading bale, gal/DMT	1	0.17	Diesel manufactured in the U.S.
Horizontal grinder, kW·h/DMT	1	36.6	Electricity generated in the U.S.
Dust collection, kW·h/DMT	1	0.17	Electricity generated in the U.S.
	2	7.26	Electricity generated in the U.S.
	3	0.46	Electricity generated in the U.S.
	4	14.5	Electricity generated in the U.S.
Miscellaneous equipment, kW·h/DMT	1	0.29	Electricity generated in the U.S.
	4	0.29	Electricity generated in the U.S.
Conveyor system, kW·h/DMT	1	0.58	Electricity generated in the U.S.
	2	0.29	Electricity generated in the U.S.
	3	0.29	Electricity generated in the U.S.

1. Depot Capacity and Farm Biomass Supply Calculations

A depot capacity is determined based on the feedstock supply ratio, which is derived by dividing the annual feedstock supply for each depot by the total annual feedstock supply for all the depots. Then, this ratio is multiplied to the constant annual biorefinery demands in order to derive the true supply feedstock of each depot. For example, in Scenario 1 (Equal Spatial Location), the total biomass input of all the depots within the 50-mile-radius is 1,442,900 dry matter tons (DMT)/year. The biomass input of Depot 1 (at Thomas) is 627,400 DMT, which is 43% of the net inputs. This percentage is then multiplied by the constant annual demands of the central biorefinery, 900,000 DMT in order to obtain the size of each depot. The final value was rounded to the nearest multiple of 5, depending on the transport distance. The calculations for the preprocessing depots are summarized in Tables S2 and S3.

Equation (S1) is used to calculate the capacity of the depots:

$$\text{Depot capacity (DC)} = \frac{\text{The annual feedstock supply for each depot}}{\text{The total feedstock supply of all depots}} \times 900{,}000 \qquad \text{(S1)}$$

Table S2. Depot capacity derived based on the demand of the single biorefinery in Scenario 1. DMT: dry matter tons.

Depot	Farms (within 50 miles)	DMT/year	Feedstock supply ratio	Depot capacity within 900,000 DMT biorefinery
Depot 1 (Thomas)	Thomas	337,200	-	-
	Sheridan	280,200	-	-
	Logan	10,000	-	-
	Total	627,400	0.43	390,000
Depot 2 (Cloud)	Cloud	45,200	-	-
	Mitchell	20,300	-	-
	Republic	15,500	-	-
	Saline	3,300	-	-
	Total	84,300	0.06	50,000
Depot 3 (Gray)	Finney	48,100	-	-
	Gray	98,900	-	-
	Hodgeman	7,200	-	-
	Haskell	22,600	-	-
	Ford	106,700	-	-
	Meade	154,800	-	-
	Total	438,300	0.30	275,000
Depot 4 (Reno)	Stafford	48,300	-	-
	Reno	47,600	-	-
	Rice	49,800	-	-
	McPherson	34,900	-	-
	Harvey	22,400	-	-
	Pratt	89,900	-	-
	Total	292,900	0.20	185,000
Net total		1,442,900	-	-

Table S3. Depot capacity derived based on the demand of the single biorefinery in Scenario 2.

Depot	Farms (within 50 miles)	DMT/year	Feedstock supply ratio	Depot capacity based on 900,000 DMT biorefinery
Depot 1 (Thomas)	Thomas	337,200	-	-
	Sheridan	280,200	-	-
	Logan	10,000	-	-
	Total	627,400	0.33	295,000
Depot 2 (Finney)	Wichita	83,400	-	-
	Scott	48,100	-	-
	Lane	12,700	-	-
	Kearny	3,700	-	-
	Finney	48,100	-	-
	Haskell	22,600	-	-
	Grant	85,200	-	-
	Gray	98,900	-	-
	Total	402,700	0.21	190,000
Depot 3 (Meade)	Seward	59,800	-	-
	Ford	106,700	-	-
	Meade	154,800	-	-
	Clark	300	-	-
	Total	321,600	0.17	150,000
Depot 4 (Stafford)	Pawnee	68,700	-	-
	Barton	16,200	-	-
	Rice	48,800	-	-
	Edwards	134,000	-	-
	Stafford	48,300	-	-
	Kiowa	54,000	-	-
	Pratt	89,900	-	-
	Total	459,900	0.24	220,000
Depot 5 (Cloud)	Cloud	45,200	-	-
	Mitchell	20,300	-	-
	Republic	15,500	-	-
	Clay	16,500	-	-
	Saline	3,300	-	-
	Total	100,800	0.05	45,000
	Net total	1,912,400	-	-

2. Feedstock Supply from Farm

Each depot consists of several farms. Each farm has its own feedstock supply that contributes to the total feedstock supply of the depot. The feedstock supply ratio is derived by dividing the feedstock supply for each farm by the total feedstock supply of all the farms for that depot within the 80 km (50-miles) radius. Since each depot has a limited capacity level, the ratio is then multiplied by the maximum capacity to obtain the true supply feedstock of each farm within the depot. The calculations for the farm feedstock supply can be found in Tables S4 and S5.

Equation (S2) is used to calculate the true feedstock supply of the farms:

$$\text{Farm biomass supply} = \frac{\text{The annual feedstock supply for each farm}}{\text{The total feedstock supply of all the farms within the depot radius}} \times \text{DC} \quad \text{(S2)}$$

Table S4. Farm supply derived based on the feedstock demands of the preprocessing depot in Scenario 1.

Depot 1 (Thomas)		**390,000 DMT/year**	**390,000**
Farms (within 50 miles)	DMT/year	Feedstock supply ratio	Farm supply within depot, 390,000 DMT/year
Thomas	337,200	0.54	209,608
Sheridan	280,200	0.45	174,176
Logan	10,000	0.02	6,216
Total	627,400	-	-
Depot 2 (Cloud)		**50,000 DMT/year**	**50,000**
Farms (within 50 miles)	DMT/year	Feedstock supply ratio	Farm supply within depot, 50,000 DMT/year
Cloud	45,200	0.54	26,809
Mitchell	20,300	0.24	12,040
Republic	15,500	0.18	9,193
Saline	3,300	0.04	1,957
Total	84,300	-	-
Depot 3 (Gray)		**275,000 DMT/year**	**275,000**
Farms (within 50 miles)	DMT/year	Feedstock supply ratio	Farm supply within depot, 275,000 DMT/year
Finney	48,100	0.11	30,179
Gray	98,900	0.23	62,052
Hodgeman	7,200	0.02	4,517
Haskell	22,600	0.05	14,180
Ford	106,700	0.24	66,946
Meade	154,800	0.35	97,125
Total	438,300	-	-
Depot 4 (Reno)		**185,000 DMT/year**	**185,000**
Farms (within 50 miles)	DMT/year	Feedstock supply ratio	Farm supply within depot, 185,000 DMT/year
Stafford	48,300	0.16	30,507
Reno	47,600	0.16	30,065
Rice	49,800	0.17	31,454
McPherson	34,900	0.12	22,043
Harvey	22,400	0.08	14,148
Pratt	89,900	0.31	56,782
Total	292,900	-	-
Net total	1,442,900	-	-

Table S5. Farm supply derived based on the feedstock demands of the preprocessing depot in Scenario 2.

Depot 1 (Thomas)		**295,000 DMT/year**	**295,000**
Farms (within 50 miles)	DMT/year	Feedstock supply ratio	Farm supply within depot, 295,000 DMT/year
Thomas	337,200	0.54	158,550
Sheridan	280,200	0.45	131,748
Logan	10,000	0.02	4,702
Total	627,400	-	-
Depot 2 (Finney)		**190,000 DMT/year**	**190,000**
Farms (within 50 miles)	DMT/year	Feedstock supply ratio	Farm supply within depot, 190,000 DMT/year
Wichita	83,400	0.21	39,349
Scott	48,100	0.12	22,694
Lane	12,700	0.03	5,992
Kearny	3,700	0.01	1,746
Finney	48,100	0.12	22,694
Haskell	22,600	0.06	10,663
Grant	85,200	0.21	40,199
Gray	98,900	0.25	46,663
Total	402,700	-	-
Depot 3 (Meade)		**150,000 DMT/year**	**150,000**
Farms (within 50 miles)	DMT/year	Feedstock supply ratio	Farm supply within depot, 150,000 DMT/year
Seward	59,800	0.19	27,892
Ford	106,700	0.33	49,767
Meade	154,800	0.48	72,201
Clark	300	0.00	140
Total	321,600	-	-
Depot 4 (Stafford)		**220,000 DMT/year**	**220,000**
Farms (within 50 miles)	DMT/year	Feedstock supply ratio	Farm supply within depot, 220,000 DMT/year
Pawnee	68,700	0.15	32,864
Barton	16,200	0.04	7,750
Rice	48,800	0.11	23,344
Edwards	134,000	0.29	64,101
Stafford	48,300	0.11	23,105
Kiowa	54,000	0.12	25,832
Pratt	89,900	0.20	43,005
Total	459,900	-	-
Depot 5 (Cloud)		**45,000 DMT/year**	**45,000**
Farms (within 50 miles)	DMT/year	Feedstock supply ratio	Farm supply within depot, 45,000 DMT/year
Cloud	45,200	0.45	20,179
Mitchell	20,300	0.20	9,063
Republic	15,500	0.15	6,920
Clay	16,500	0.16	7,366
Saline	3,300	0.03	1,473
Total	100,800	-	-
Net total	1,912,400	-	-

3. Monte Carlo Simulation

Table S6. Results of the Monte Carlo Simulation presenting the life cycle GHG emissions for 1000 trials of uncertainty analysis. SD: standard deviation; IPCC: intergovernmental panel on climate change; and GWP: global warming potential.

Impact category	Unit	Scenario	Mean	Median	SD	Coefficient of variation	5%	95%	Standard error of mean
IPCC GWP 100 years	g CO_2/MJ [1]	Equal region	26.11	24.96	5.09	0.19	22.53	34.81	0.16
-	-	Biomass weighted and transport distance	25.17	24.32	2.96	0.11	22.44	32.38	0.09

[1] The GHG emission is converted from kg CO_2/dry metric ton. The unit conversion from kgCO_2 e/DMT to gCO_2 e/MJ ethanol is 3.54×10^{-4}.

Table S7. Input data and distribution function type for the Monte Carlo Simulation. All units in g CO_2e/MJ ethanol.

Scenario 1	19 counties			
	Minimum	Average	Maximum	Distribution function type
Feedstock harvest, collection and storage	0.013	0.32	1.41	Lognormal [a]
Transport from field	0.089	0.20	0.96	Lognormal [a]
Preprocessing depot	0.04	1.00	4.54	Lognormal [b]
Transport from depots	0.09	2.00	9.62	Lognormal [b]
Scenario 2	**27 counties**			
	Minimum	**Average**	**Maximum**	**Distribution function type**
Feedstock harvest, collection and storage	0.0009	0.22	1.07	Lognormal [c]
Transport from field	0.0006	0.15	0.72	Lognormal [c]
Preprocessing depot	0.003	0.72	3.44	Lognormal [d]
Transport from depots	0.006	1.50	7.28	Lognormal [d]

[a] Selected among 11 distribution function types by Oracle Crystal Ball statistical software (Oracle Corporation, Redwood City, CA, USA) [1], with maximization of goodness-of-fit method to the data compiled from 19 farms; [b] Selected among 11 distribution function types by Oracle Crystal Ball statistical software, with maximization of goodness-of-fit method to the data compiled from four depots; [c] Selected among 11 distribution function types by Oracle Crystal Ball statistical software, with maximization of goodness-of-fit method to the data compiled from 27 farms; [d] Selected among 11 distribution function types by Oracle Crystal Ball statistical software, with maximization of goodness-of-fit method to the data compiled from five depots.

Table S8. Energy inputs for feedstock production. PTO: power take-off; GHG: greenhouse gas; and INL: Idaho National Laboratory.

Processes		Current paper		Wang *et al.* [2]		Larson *et al.* [3]		Eranki *et al.* [4]	
		Energy consumption (MJ/DMT)	**Assumptions**	**Energy consumption (MJ/DMT)**	**Assumptions**	**Energy consumption (MJ/DMT)**	**Assumptions**	**Energy consumption (MJ/DMT)**	**Assumptions**
Harvesting	Combine harvesting (U.S. electricity)	118.7	Harvesting 3.4 short ton of corn stover per acre. The inventory takes into account the diesel fuel consumption and the amount of agricultural machinery and of the shed, which has to be attributed to the harvesting by combined harvester. Also taken into consideration is the amount of emissions to the air from combustion and the emission to the soil from tyre abrasion during the work process.	-	-	-	-	-	-
	Twin bar rake with 180 HP tractor	27.5	Raking 1.73 short ton of corn stover per acre. The inventory takes into account the diesel fuel consumption and the amount of agricultural machinery and of the shed, which has to be attributed to the harvesting by combined harvester. Also taken into consideration is the amount of emissions to the air from combustion and the emission to the soil from tyre abrasion during the work process.	-	-	-	-	-	-
	Bailing	60.2	Baling 2.4 short ton of stover per acre of land. Data are based on INL conventional biomass logistics design. Assumes 175-HP tractor and PTO flail-shredder and windrower. Includes emissions from diesel combustion and infrastructure. Does not include emissions from tire abrasion and dust, *etc.*	-	-	-	-	-	-

Table S8. *Cont.*

Processes		Current Paper		Wang *et al.* [2]		Larson *et al.* [3]		Eranki *et al.* [4]	
		Energy consumption (MJ/DMT)	**Assumptions**	**Energy consumption (MJ/DMT)**	**Assumptions**	**Energy consumption (MJ/DMT)**	**Assumptions**	**Energy consumption (MJ/DMT)**	**Assumptions**
Subtotal (harvesting)		206.4	-	379	Fertilizer production and fossil fuel use for farming are significant GHG emission sources.	677.5	Harvesting corn stover involves mowing, raking into windrows, fiel-drying to 15% moisture, and then square-bailing. Mowing occurs during harvest of the primary crop and shredding is required before raking.	-	-
Collection	Self propelled stacker	41.3	Stacking 2.4 short ton of corn stover per acre.	-	-	-	-	-	-
Subtotal (collection)		41.3	-	219	The amount of nutrients lost with stover removal would be supplemented with synthetic fertilizers.	57	After baling, a Stinger Stacker 4400 collects and piles bales at field edge for manual tarping with the help of a telescopic handler.	-	-
Feedstock production (harvesting + collection)		247.7	-	598	-	734.5	-	4,274	Processing energy and emissions were obtained from the NREL/Dartmouth Aspen plus biorefinery model (National Renewable Energy Laboratory, Golden, CO, USA [5]).

Figure S1. Map of Kansas presenting the distribution and density of corn stover supply by county. The biorefinery is located at the centroid of Reno county (red frame).

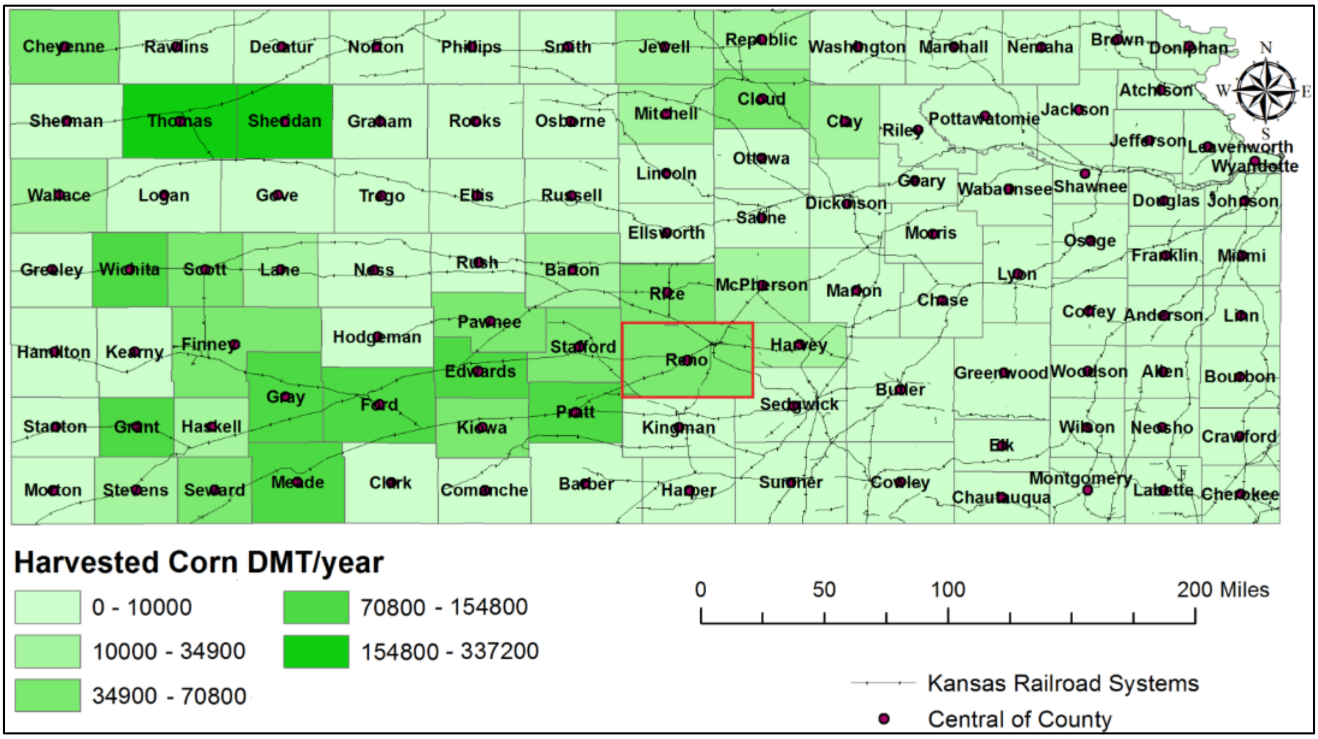


Figure S2. Histogram representing life cycle GHG emissions within 90% confidence interval in Scenario 1.

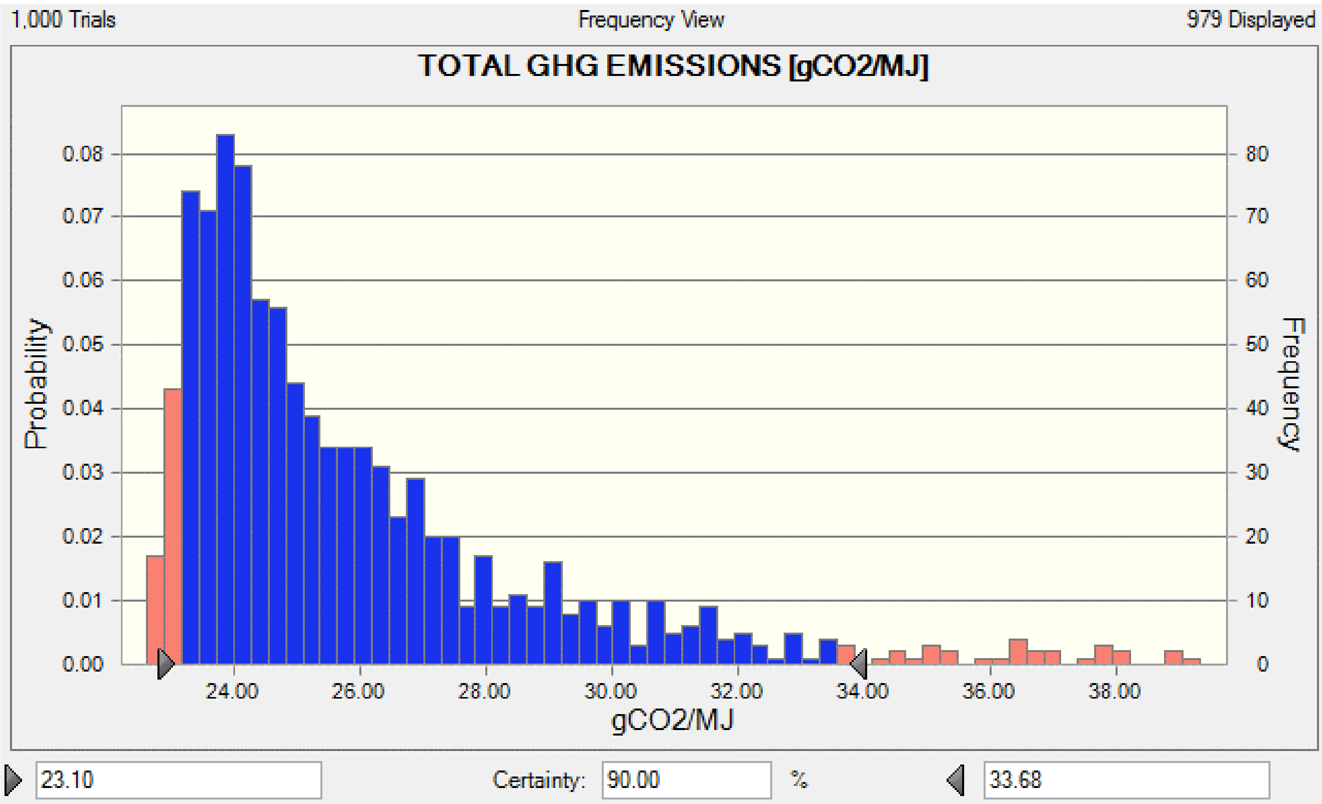
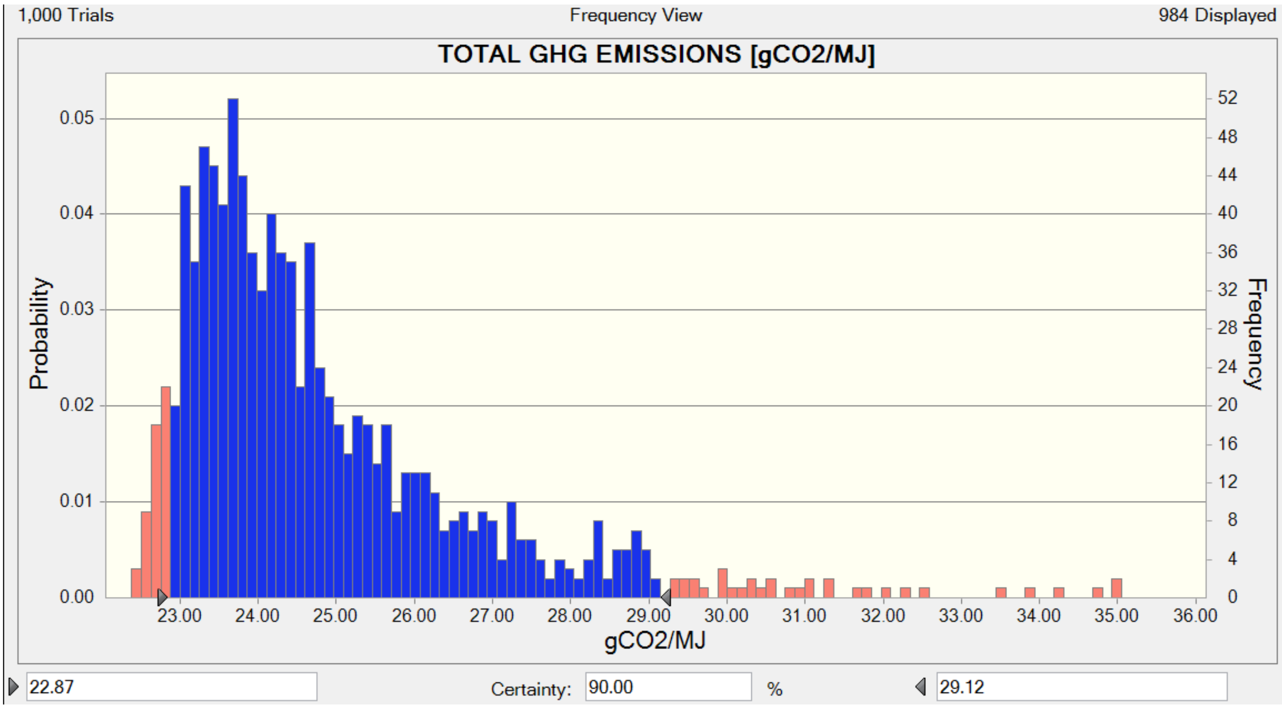


Figure S3. Histogram representing life cycle GHG emissions within 90% confidence interval in Scenario 2.



4. Matlab Code Description

The energy consumption output data from Biomass Logistics Model (BLM) developed using Powersim™ at Idaho National Laboratory (INL) (Idaho Falls, ID, USA) [6] were presented in an excel spreadsheet. The database of four processes in the bio-ethanol supply chain was exported to the excel files from SimaPro v.7.3.3. Processes are ranked from 1 to 4, which represent the order of four processes in the supply chain: (1) harvest; (2) transport from field; (3) preprocessing depot; and (4) transport from depot. A Matlab script, namely Readcode.m is used to access the values from the BLM output. These values are corresponding to the parameters in SimaPro spreadsheet for each unit process. A Matlab function, autoGenCells.m, was written in order to replace the values in the SimaPro spreadsheet with the corresponding values from the BLM output. Then, the function multiplies these values to the GHG emission of each sub-process (*i.e.*, electricity, diesel, *etc.*), which was generated by the SimaPro 7.3.3. Finally, the function sums the GHG emission of all sub-processes in order to calculate the GHG emission of the process.

4.1. Readcode.m

This file reads all the values from the BLM output spreadsheet and fills in the spots in the SimaPro Process spreadsheet. It also keeps track of each resource used.

For attributes follow the legend below:

- D: diesel used
- E: electric used
- X: unknown attribute

Filenames and sheets

```
fromFile = 'Depot_Drexel.xlsx';
toFileDepot = 'Corn Stover,depot operations,Advanced.xls';
toFileField = 'Corn stover, field operations, conventional, 2010 INL test';
fromSheet = 'Sheet1';
toSheetDepot = 'Sheet2';
toSheetField = 'Sheet3'.
```

Generate destination cells automatically

```
[fromCellsDepot toCellsDepot attributeDepot] = autoGenCells(toFileDepot);
[fromCellsField toCellsField attributeField] = autoGenCells(toFileField);
```

Record so we can multiply with amounts later on

```
dataToRecordDepot = zeros(length(fromCellsDepot),1);
dataToRecordField = zeros(length(fromCellsField),1);
totalDiesel = 0;
totalElectric = 0.
```

Copying of data (example for only the preprocessing depot and harvest operations processes)

The Preprocessing depot

```
for ii = 1:length(fromCellsDepot)
  try
    [~,~,data] = xlsread(fromFile,fromSheet,fromCellsDepot{ii});
  if ~isnumeric(data)
      data = 0;
    end
  catch Exception
    data = 0;
  end
  xlswrite(toFileDepot,data,toSheetDepot,toCellsDepot{ii});
  dataToRecordDepot(ii) = data;
  switch attributeDepot(ii)
    case 'D'
      totalDiesel = totalDiesel + data;
    case 'E'
      totalElectric = totalElectric + data;
  end
  disp(data)
end
```

The Harvest, Collection and Storage

```
for ii = 1:length(fromCellsField)
    try
        [~,~,data] = xlsread(fromFile,fromSheet,fromCellsField{ii});
        if ~isnumeric(data)
            data = 0;
        end
    catch Exception
```

4.2. AutoGenCells.m

Procedures:

(1) Read toFile and find the cells that start with 'INL_'. These are the areas we need to fill.
(2) Extract the full names.
(3) Extract their locations in Excel. This will be their toCells entry.
(4) One by one, find the corresponding Excel reference.
(5) Look to the right of the reference and find the cell it is pointing.
(6) This will be the fromCells entry.

```
function [fromCells toCells attribute] = autoGenCells(toFile)
        count = 0;
        attribute = [];
        [~,~,raw] = xlsread(toFile);
        [a ~] = size(raw);
        for ii = 1:a
            temp = strfind(raw{ii,2},'INL_');
            if ~isempty(temp)
```

<u>Finding text</u>

```
                count = count + 1;
                toCells{1,count} = ['B' num2str(ii)];
                fullname = raw{ii,2};
```

<u>Check for attributes before doing anything</u>

```
                if ~isempty(strfind(raw{ii,1},'Electricity'))
                    attribute = [attribute 'E'];
                elseif ~isempty(strfind(raw{ii,1},'Diesel'))
                    attribute = [attribute 'D'];
                else
                    attribute = [attribute 'X'];
                end
```

Finding where the values in the BLM Excel spreadsheet

```
          for jj = ii:a
             temp2 = strfind(lower(raw{jj,1}),lower(fullname));
             if ~isempty(temp2)
                % we found the reference
                ref = raw{jj,2};
                refs = regexp(ref,'!','split');
                fromCells{1,count} = refs;
             end
          end
       end
    end
clear all
close all
clc
```

5. Paired-Samples *T*-Test

Table S9. Paired samples statistics.

Pair 1	Mean	*N*	SD	Standard error of the mean
Scenario1_Total	31.4678	1000	5.12564	0.16209
Scenario2_Total	27.9610	1000	3.16813	0.10019

Table S10. Paired samples test.

Mean	-	3.5
SD	-	1.95
Standard error of the mean	-	0.06
90% confidence interval of the difference	Lower	3.4
	Upper	3.6
t	-	56.65
df	-	999
Sig. (two-tailed)	-	0

Null hypothesis: $\mu_{\text{GHG emissions, scenario 1}} = \mu_{\text{GHG emissions, scenario 2}}$.

Alternative hypothesis: $\mu_{\text{GHG emissions, scenario 1}} \neq \mu_{\text{GHG emissions, scenario 2}}$.

This is a two-tailed test with $\alpha = 0.1$ (90% confidence interval). The descriptive statistics of two scenarios are described in Table S9. The two-tailed *p* value is less than 0.001. In order to reject the null hypothesis, the *p*-value has to be less than alpha. In this analysis, *p*-value < α (Table S10), and thus rejecting the null hypothesis. Therefore, the results imply that the mean values of two scenarios are statistically different.

References

1. *Forecasting and Risk Analysis for Spreadsheet Users*; Oracle Crystal Ball Release 11.1.2.3.500; Oracle Corporation: Redwood City, CA, USA, 2014.
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4. Eranki, L.P.; Dale, E.B. Comparative life cycle assessment of centralized and distributed biomass processing systems combines with mixed feedstock landscapes. *Glob. Chang. Biol. Bioenergy* **2011**, *3*, 427–438.
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6. Muth, D.J.; Langholtz, M.H.; Tan, E.C.D.; Jacobson, J.J.; Schwab, A.; Wu, M.M.; Argo, A.; Brandt, C.C.; Cafferty, K.G.; Chiu, Y.-W.; *et al.* Investigation of thermochemical biorefinery sizing and environmental sustainability impacts for conventional supply system and distributed pre-processing supply system designs. *Biofuels Bioprod. Biorefining* **2014**, *8*, 545–567.