Supporting Information for "Biofuels, Land Use Change and Greenhouse Gas Emissions: Some Unexplored Variables"

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Farming sites

We selected the following 40 counties for farming sites for modeling: (see Figure S1)

Iowa: Boone, Delaware, Hamilton, Hancock, Humboldt, Johnson, Linn, Palo Alto and Webster,

Illinois: Bureau, Champaign, Macon, Peoria and Tazewell,

Indiana: Adams, Allen, Delaware, Wells and Whitley,

Michigan: Calhoun, Eaton, Hillsdale, Jackson and Kalamazoo,

Minnesota: Becker, Otter Tail and Todd,

Nebraska: Adams, Buffalo, Clay, Dawson, Fillmore, Hall and Saline,

Ohio: Montgomery,

South Dakota: Brown, Edmunds and Spink,

Wisconsin: Columbia and Sauk

Note that some counties do not have biorefineries, but its adjacent counties have biorefineries (*1*).

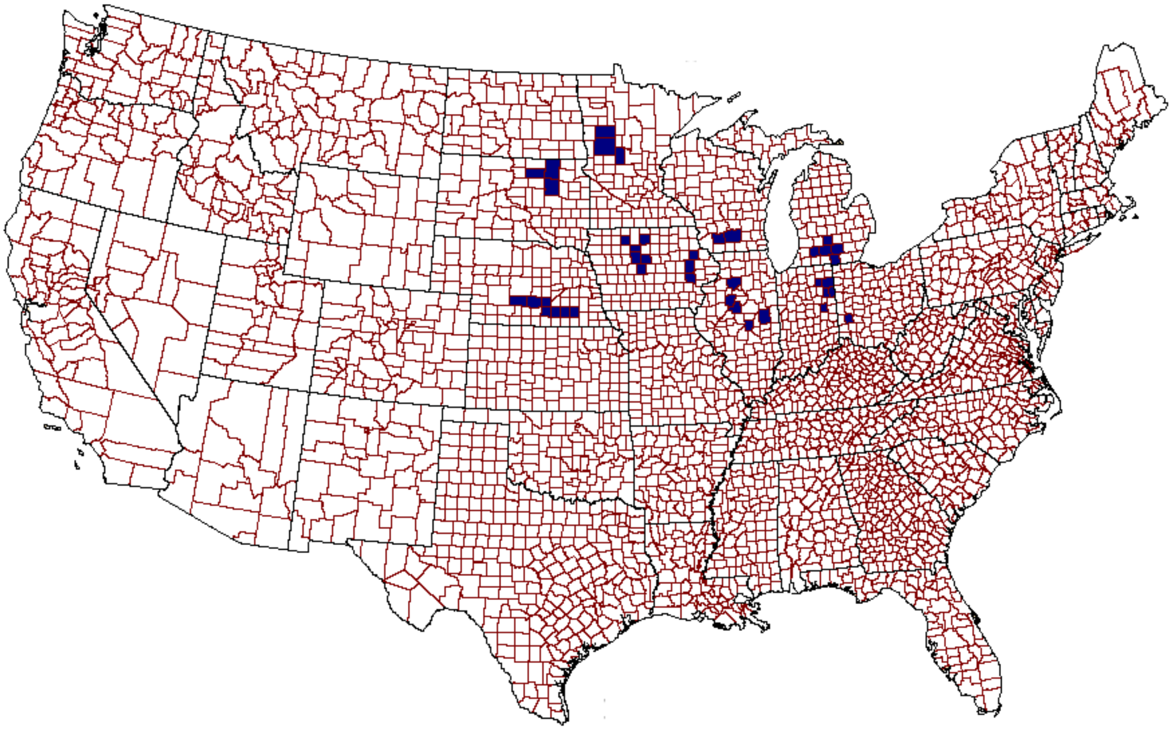

Figure S1. Farming sites for modeling

Fraction of conservation tillage in the current practice

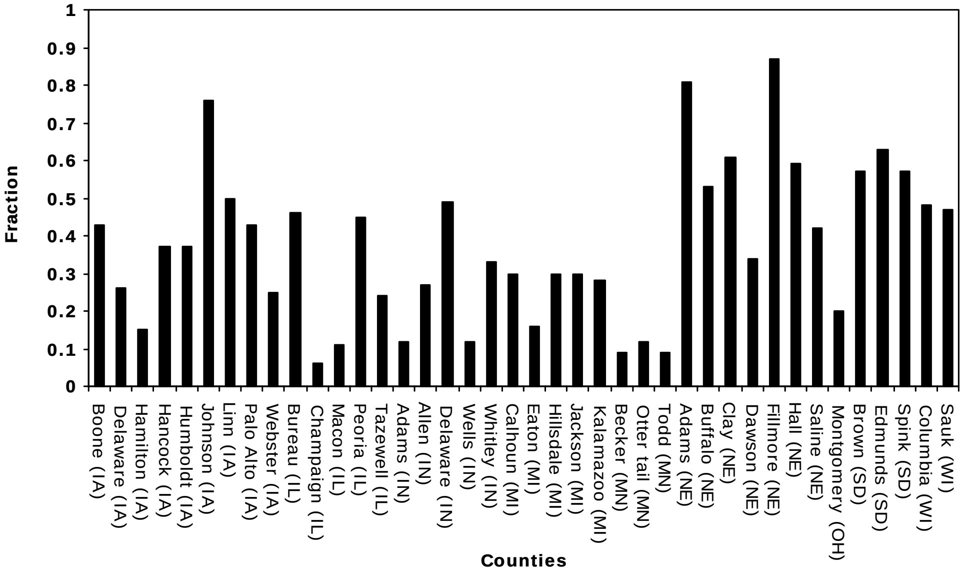

Figure S2. Fraction of conservation tillage in the current practice (*2*)

System boundary

The system boundaries are illustrated in Figure S3. Without the E85 fuel system, society relies on the gasoline fuel system depicted in the right hand side of Figure S3. When the E85 fuel system is introduced, the E85 fuel system displaces the gasoline fuel system. Processes in the gasoline fuel systems (right hand side) are included in the analysis as GHG credits.

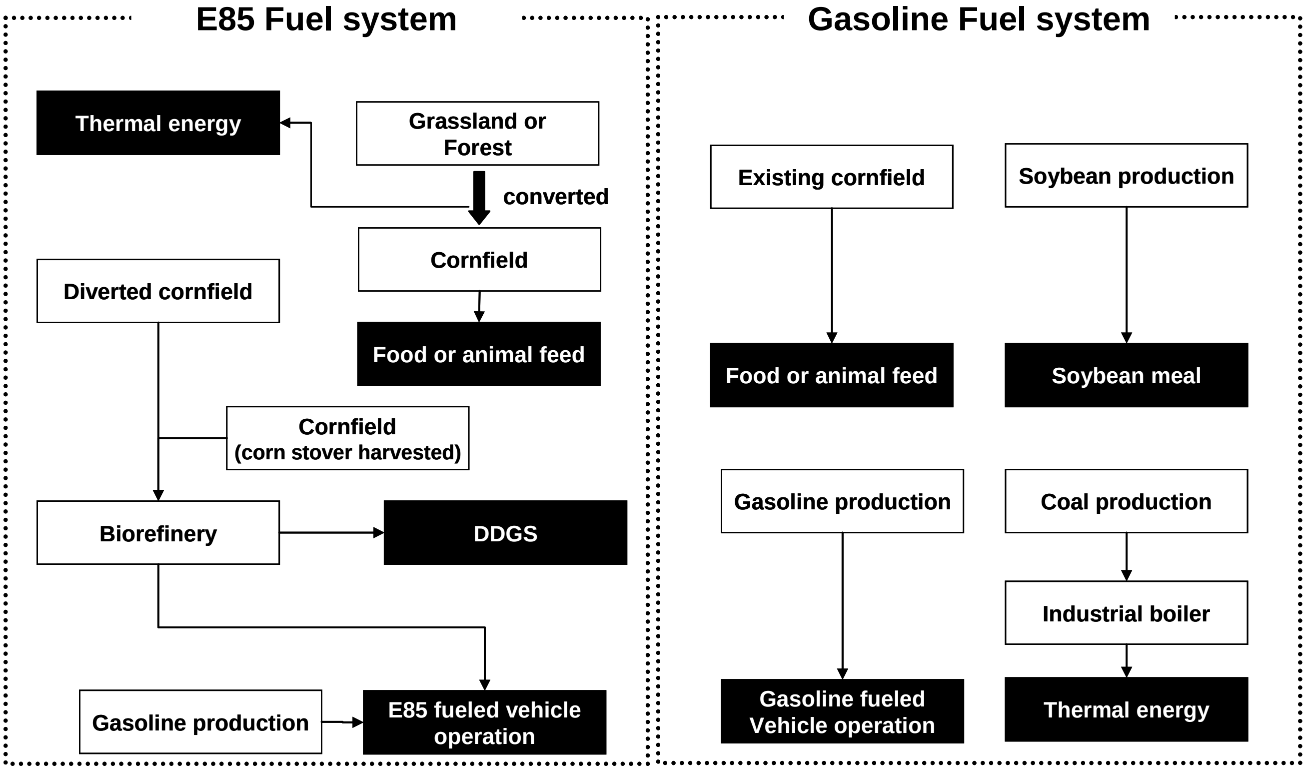

Figure S3. System boundaries [black boxes represent products]

Results from the DAYCENT simulations

Soil organic carbon (SOC) levels in the grassland and the forest conversion cases are illustrated in Figures S4 and S5. We run the DAYCENT model with temperate grass for >10,000 years (the "spin up" process) to predict SOC dynamics in temperate grassland. Grassland is converted to cornfield at year zero via land clearing. SOC dynamics in grassland are likely at a steady state before the conversion event. Conversion of grassland to no-tilled cornfield combined with winter cover crop practices sequesters more carbon into soil as SOC than native grassland does despite an initial decline in SOC levels. SOC levels in no-tilled cornfield converted from grassland initially decrease and then gradually increase. Note that SOC levels in no-tilled cornfield in some counties do not exceed initial SOC levels in grassland for 100 years, while initial SOC levels are exceeded before 100 years for other counties. The initial declines in SOC after the conversion event are due land clearing. SOC levels decrease until a steady state is achieved in plowed cornfield or cornfield under the current tillage practices converted from grassland continuously. We run the DAYCENT model with mixed forest (coniferous forest (50 %) and deciduous forest (50%)) for >10,000 years to predict SOC dynamics in forest lands. SOC dynamics in cornfield converted from forest show similar patterns to those in cornfield converted from grassland. SOC levels in no-tilled cornfield converted from forest continuously decrease within 100 cropping year period. The simulations show that tillage practices in converted cornfield are critical in maintaining SOC levels.

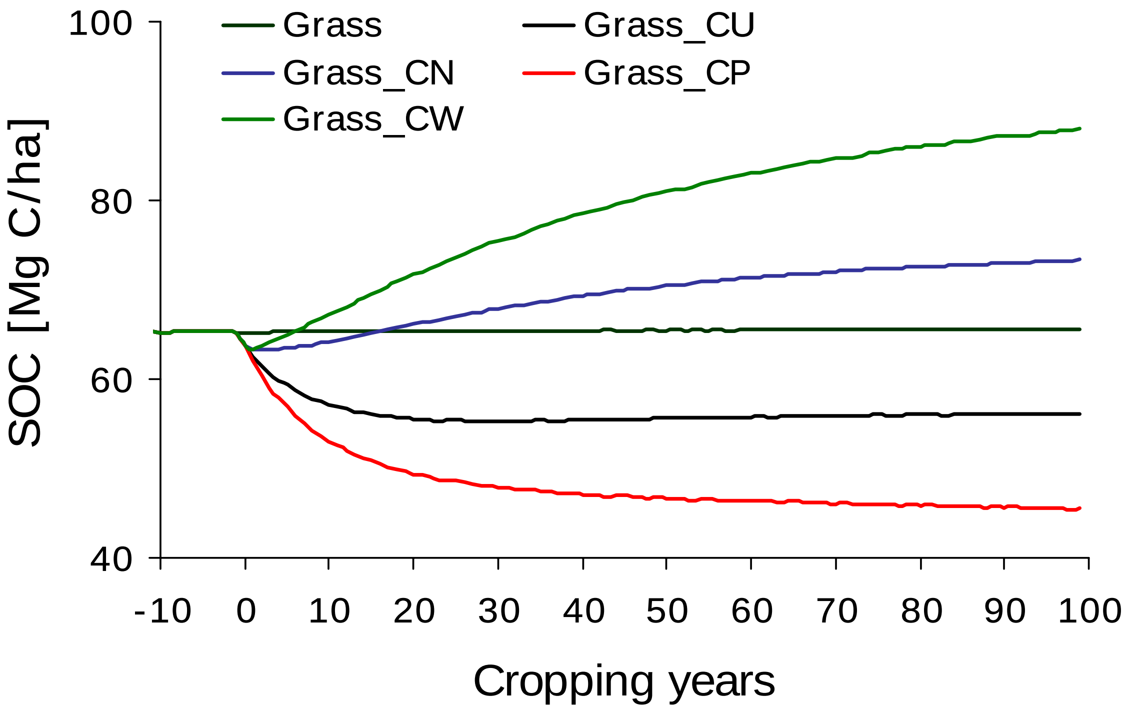

Figure S4. Mean SOC levels in the grassland conversion scenario over forty counties in the top 20 cm depth [Grass: SOC levels in undisturbed grassland; Grass_CU: SOC levels in cornfield converted from grassland under the current tillage practices; Grass_CN: SOC levels in no-tilled cornfield converted from grassland; Grass_CP: SOC levels in plowed cornfield converted from grassland; Grass_CW: SOC levels in no-tilled cornfield converted from grassland combined with winter cover crop practice]

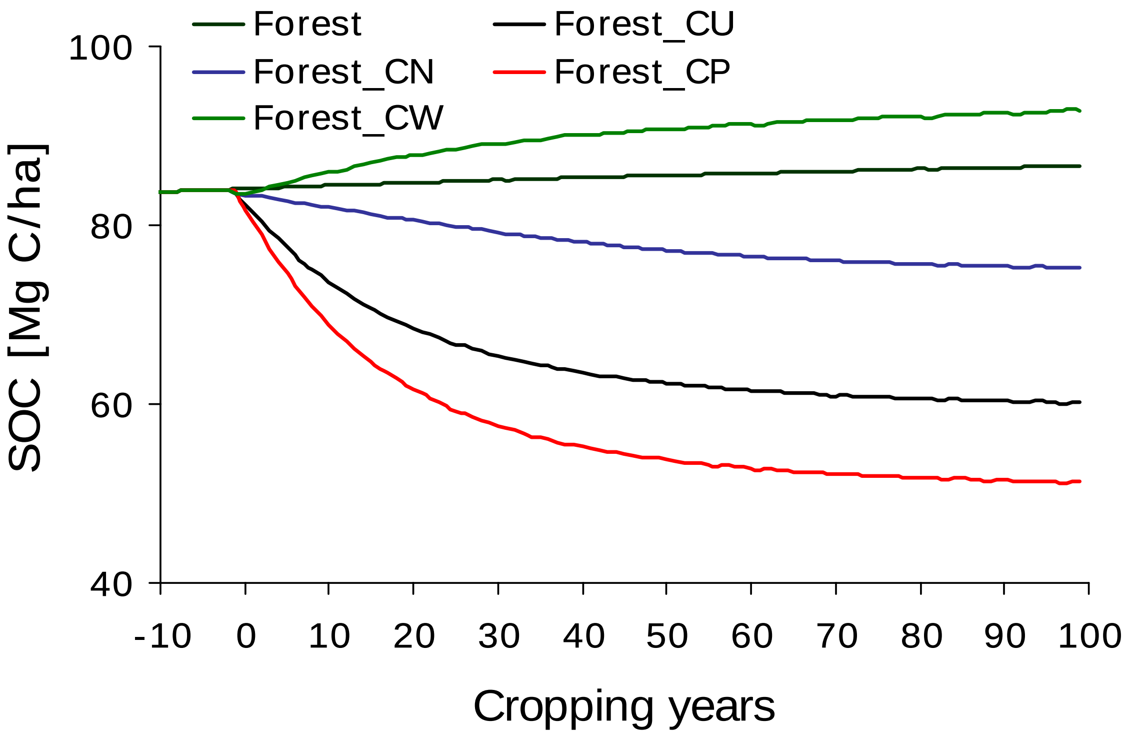

Figure S5. Mean SOC levels in the forest conversion scenario over forty counties in the top 20 cm depth [Forest: SOC levels in undisturbed forest; Forest_CU: SOC levels in cornfield converted from forest under the current tillage practices; Forest_CN: SOC levels in no-tilled cornfield converted from forest; Forest_CP: SOC levels in plowed cornfield converted from forest; Forest_CW: SOC levels in no-tilled cornfield converted from forest combined with winter cover crop practice]

Figure S6 shows simulated SOC levels in continuous corn agriculture. The simulations predict that no tillage practice could enhance SOC levels, but plow tillage could decrease SOC levels because of soil disturbance. The simulation results are consistent with experimental studies (*3, 4*). However, Baker and his colleagues (*5*) recently showed that the carbon sequestration observed under no till in most previous studies may be merely due to the sampling depths (0 – 30 cm). Blanco-Canqui and Lal (*6*) observe that no tillage increases SOC levels in the surface soil layers (0 – 30 cm), but plow tillage sequesters more carbon than no tillage for the whole soil profile. On the contrary, Angers and Eriksen-Hamel (*7*) conclude that the greater SOC levels at plow depth under plow tillage do not completely offset the gain under no tillage in the surface soil layer. Based on current knowledge, the results from the DAYCENT simulations may or may not reflect the reality if the soil depth is extended to whole soil profile. Further investigations on the effects of soil depth on SOC level are needed.

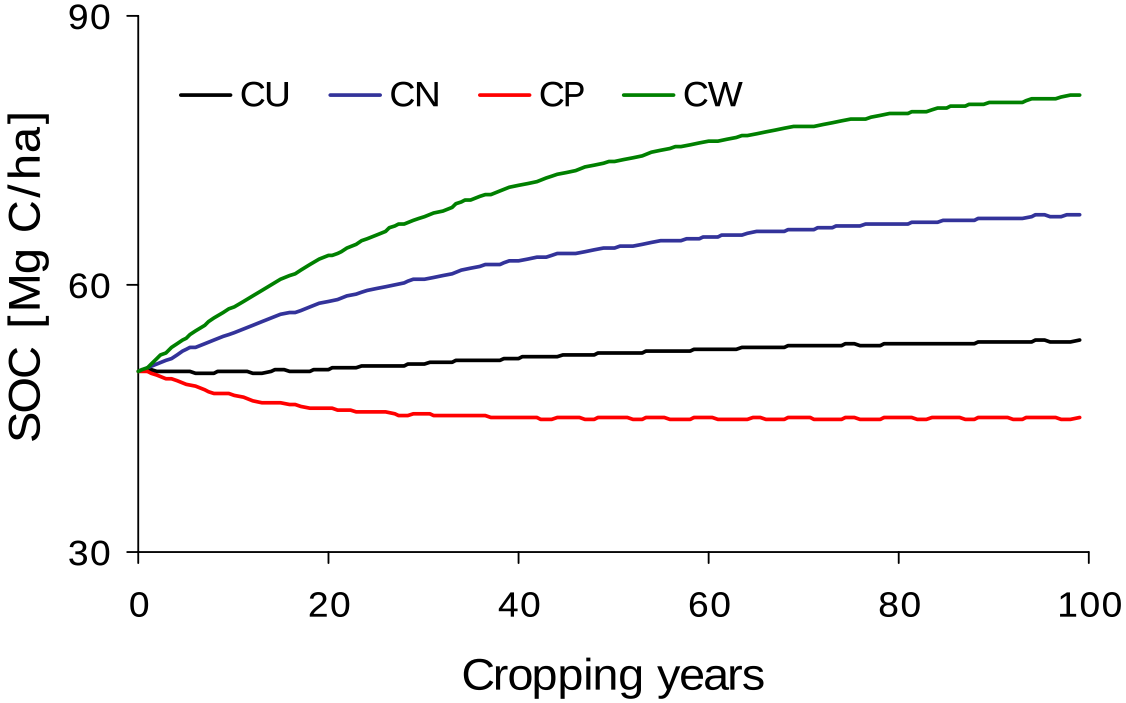

Figure S6. Mean SOC levels in a cornfield in the top 20 cm depth [CU: current tillage; CN: no tillage; CP: plow tillage; CW: winter cover crop practice combined with no tillage]

Data sources

Table S1. Data sources

Process	Data sources
Agronomic inputs in corn and soybean culture	(*8, 9*)
Fuel consumption in corn and soybean culture	(*10*)
Fertilizers and agrochemicals	(*11*)
Dry milling, soybean crushing process, and transportation/distribution of ethanol	(*12*)
Energy system (e.g., gasoline, electricity, etc.)	(*12 - 15*)
Corn stover harvesting and transportation of corn stover	(*12*)
Wood harvesting and transportation of wood	(*12*)
Industrial coal-fired boiler	(*13, 14*)
Vehicle operations (i.e., gasoline fueled and E85 fueled)	(*12*)

Parameter projection

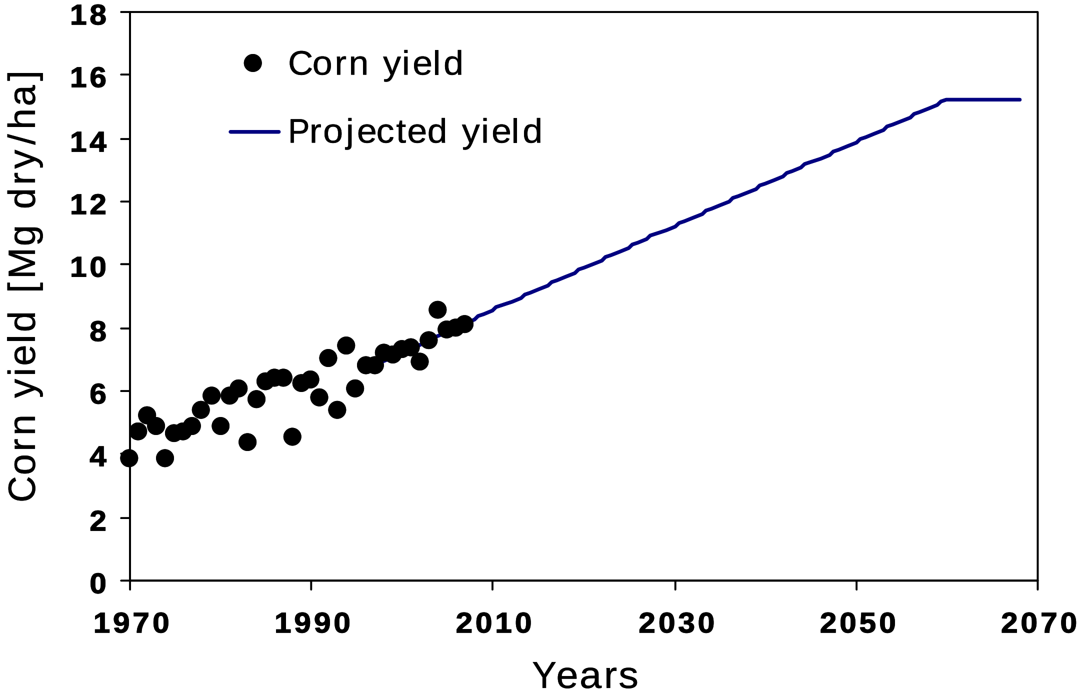

Figure S7. Projected corn yield [filled circles: actual corn yield (*8*)]

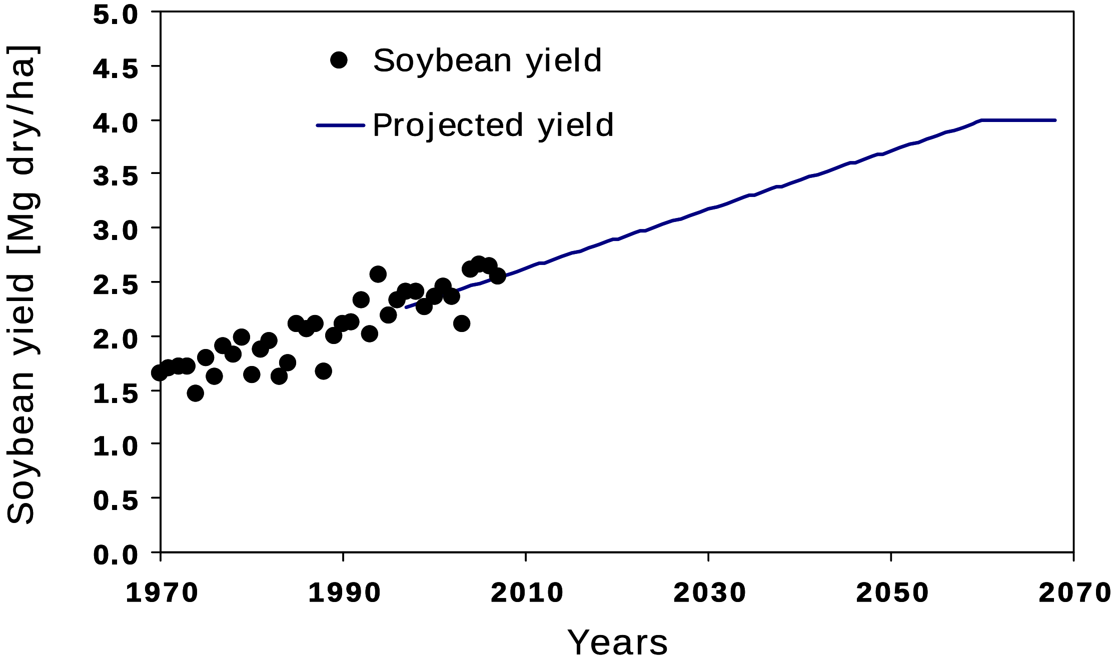

Figure S8. Projected soybean yield [filled circles: actual corn yield (*8*)]

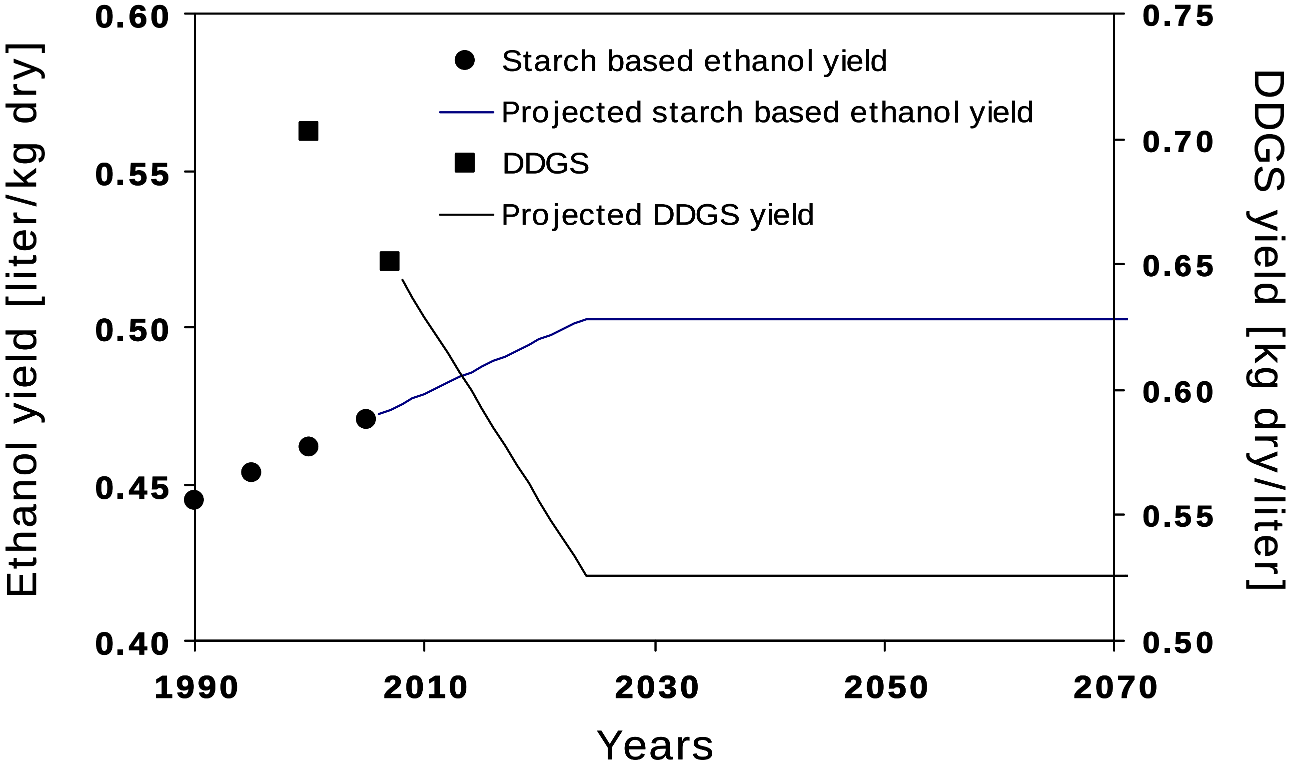

Figure S9. Projected ethanol yield and DDGS yield [filled circles: yield from the GREET model (*12, 16*) and filled squares: DDG yield from the GREET model (*12, 16*)] We assume that the maximum ethanol yield is about 97 % of the theoretical ethanol yield (*17*).

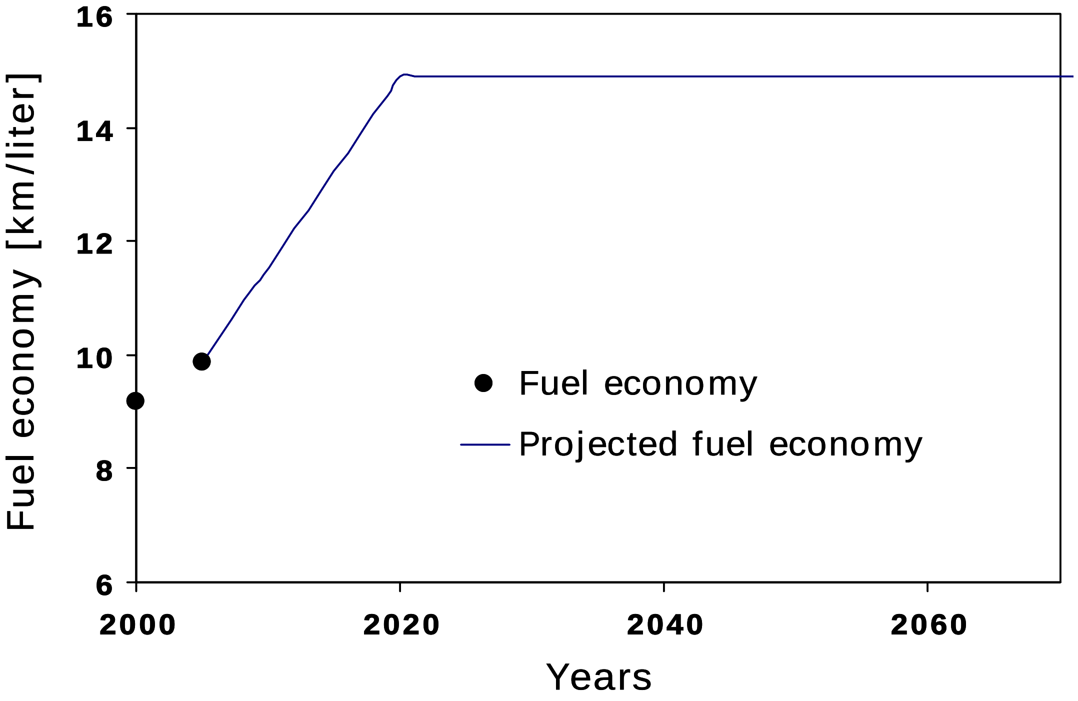

Figure S10. Projected fuel economy [filled circles: fuel economy from the GREET model (*12, 15*); liter is gasoline-equivalent liter] The U.S. government states that the fuel economy must reach 14.9 km per liter (~35 mile per gal) by 2020 (*18*).

GHG emissions associated with carbon debt when wood is utilized as solid fuel

$$
\begin{aligned}
\left[\text{GHG from carbon debt}\right]_{\text{u}} = {} & \text{GHG from biomass loss} \\
& + \text{GHG from combustion of wood} \\
& + \text{GHG from energy used in harvesting} \\
& + \text{GHG from energy used in transportation of wood} \\
& - \text{GHG from combustion of coal}
\end{aligned}
\qquad (1)
$$

where GHG from biomass loss is the GHG emissions associated with carbon losses from existing biomass during the land conversion event. GHG from combustion of wood is the GHG emissions associated with combustion of wood.. GHG from energy used in harvesting is the GHG emissions associated with harvesting wood, and GHG from energy used in transportation of wood is the GHG emissions associated with transportation of wood from the forest to an industrial boiler. GHG from combustion of coal is the GHG emissions associated with combustion of coal displaced by wood, including GHG emissions from precombustion processes.

GHG emissions associated with indirect LUC

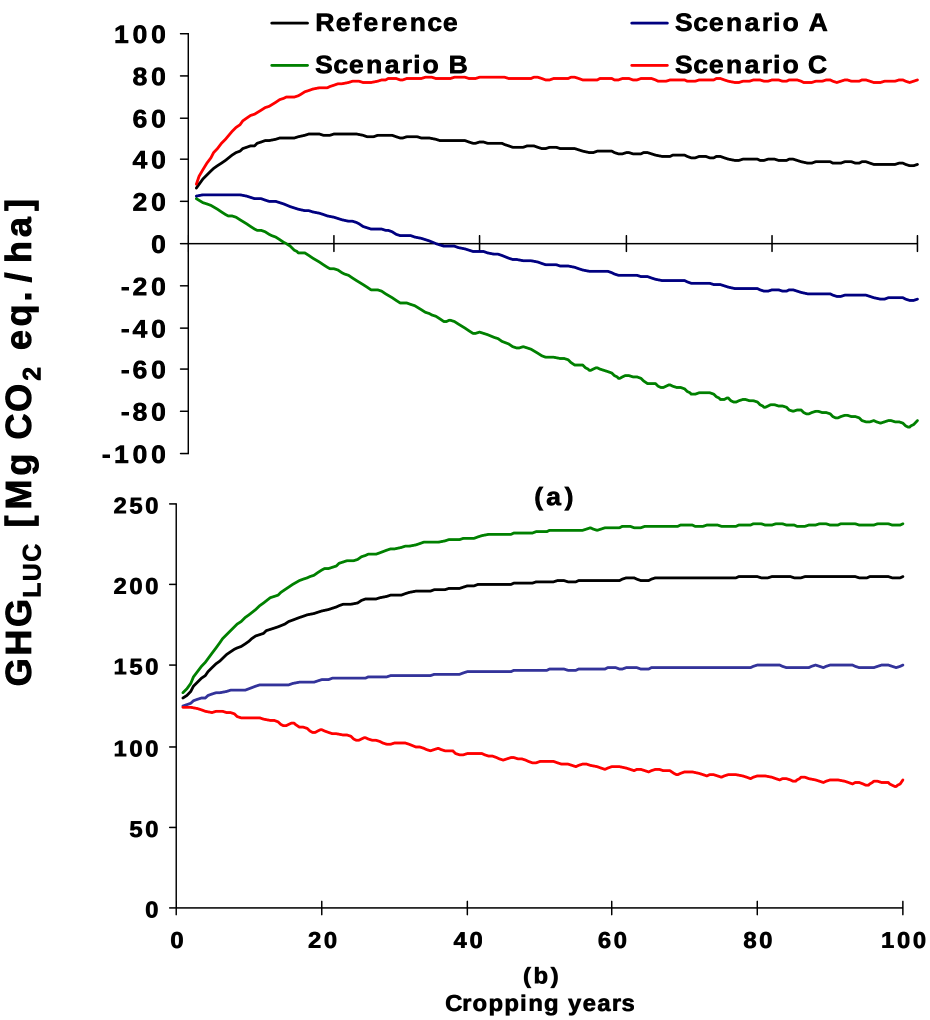

Figure S11. Indirect GHG_{LUC} (a) grassland conversion case; (b) forest conversion case

Cumulative GHG benefits of the E85 fuel system in each county

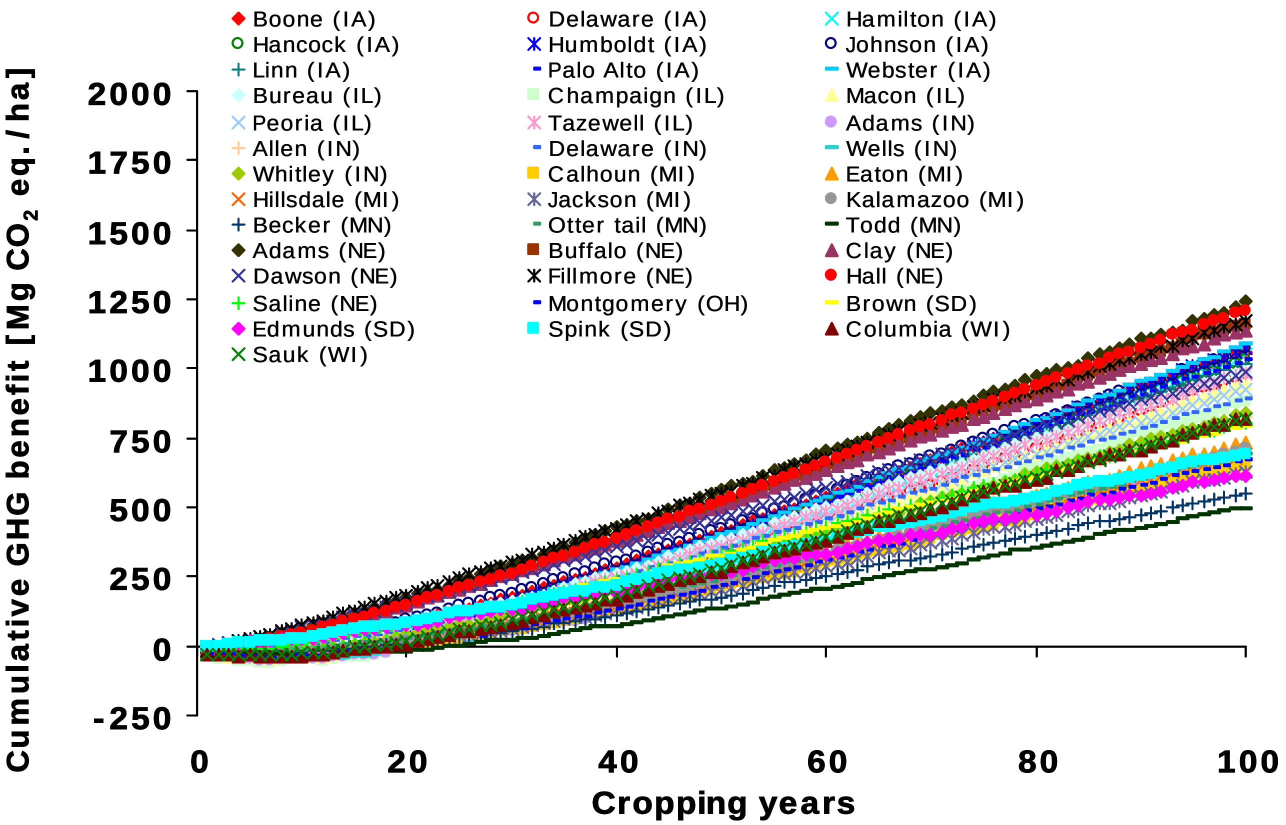

Figure S12. Cumulative GHG benefits of the E85 fuel system in individual counties in the grassland conversion case (reference case)

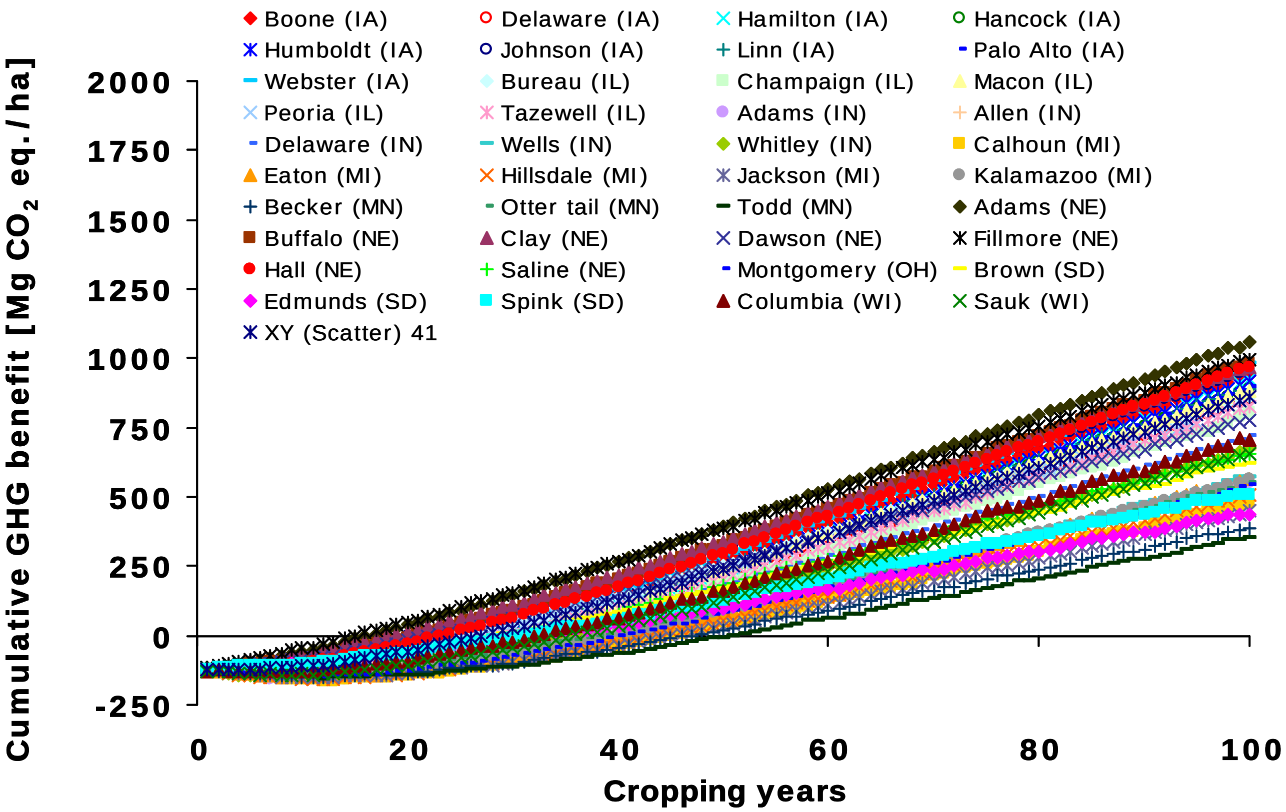

Figure S13. Cumulative GHG benefits of the E85 fuel system in individual counties in the forest conversion case (reference case)

Cumulative GHG benefits of the E85 fuel system

Corn culture & Trp: GHG emissions associated with corn culture and transportation of corn to a corn dry mill plant

Direct LUC: GHG emissions associated with direct land use change in existing cornfield

Indirect LUC: GHG emissions associated with indirect land use change in newly converted cornfield

Biorefinery & Trp: GHG emissions associated with biorefinery, corn stover production/transportation, and transportation/distribution of ethanol

Credit from DDGS: GHG credit associated with the DDGS displacement

E85 fueled vehicle: GHG emissions associated with operating an E85 fueled vehicle and an gasoline used in E85 fuel

Gasoline fueled vehicle: GHG emissions associated with operating a gasoline fueled vehicle and gasoline production

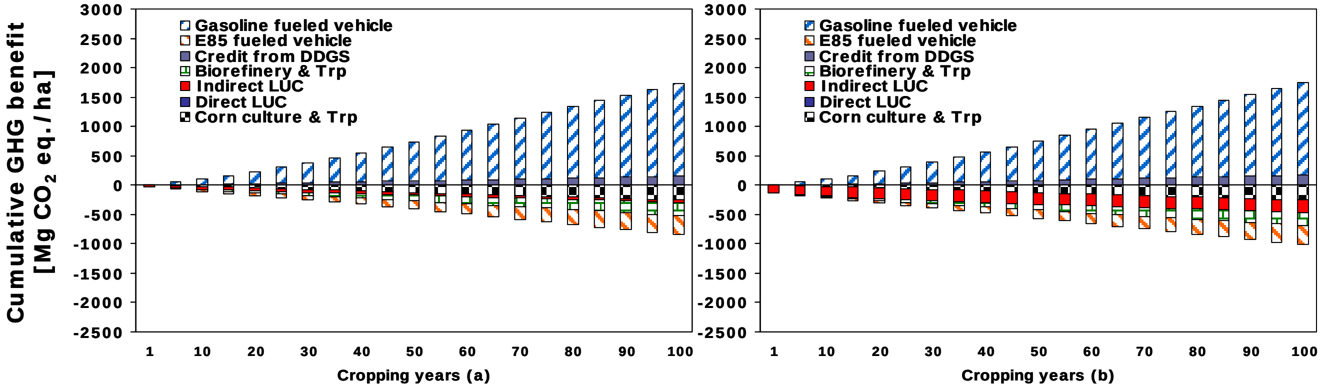

Figure S14. Cumulative GHG benefits of the E85 fuel system under the reference case: (a) grassland conversion case; (b) forest conversion case

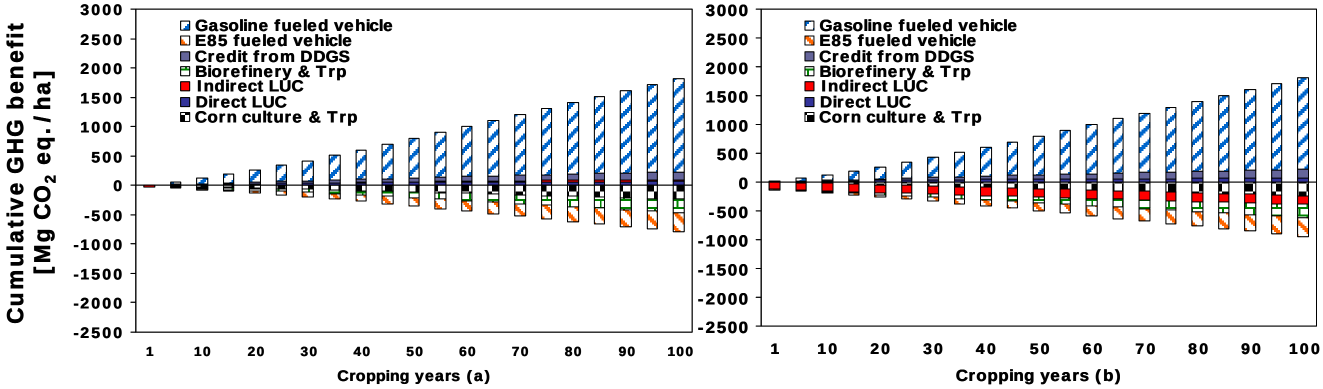

Figure S15. Cumulative GHG benefits of the E85 fuel system in scenario A: (a) grassland conversion case; (b) forest conversion case

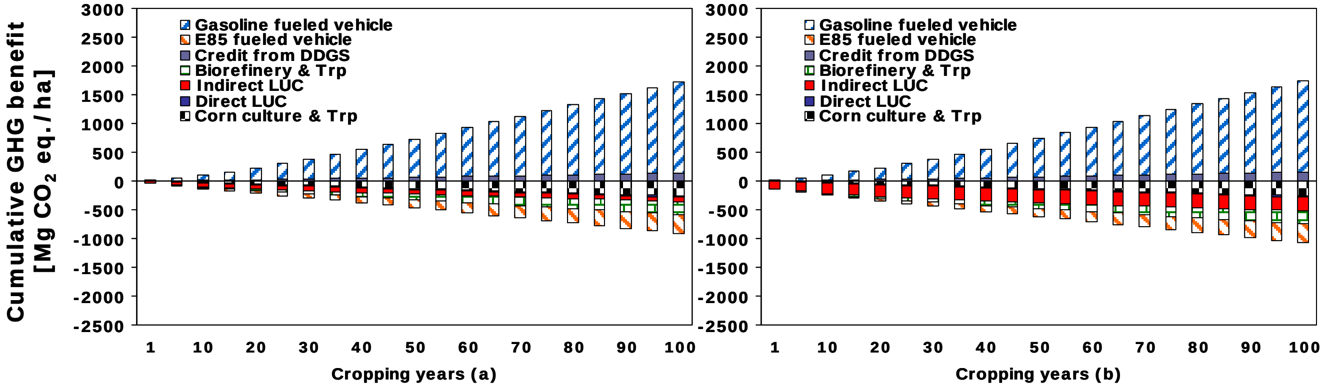

Figure S16. Cumulative GHG benefits of the E85 fuel system in scenario B: (a) grassland conversion case; (b) forest conversion case

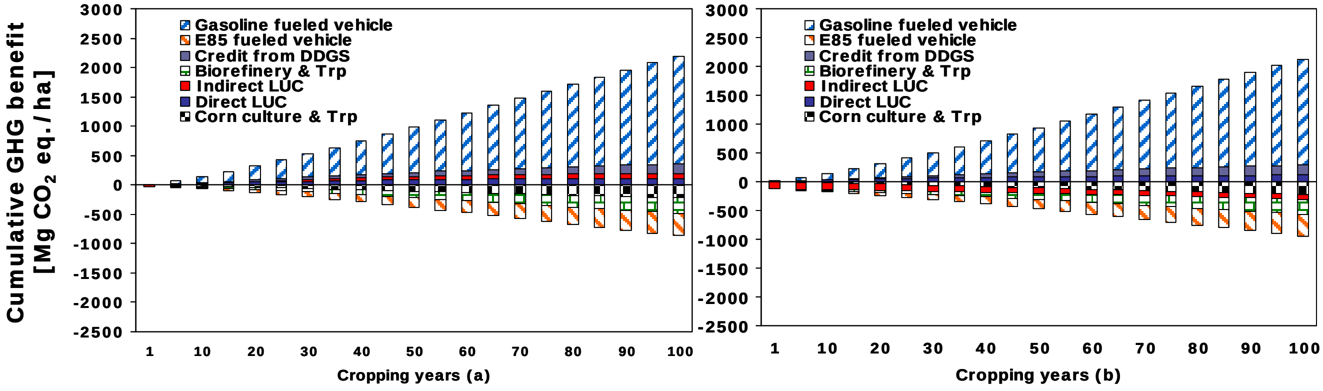

Figure S17. Cumulative GHG benefits of the E85 fuel system in scenario C: (a) grassland conversion case; (b) forest conversion case

Payback periods

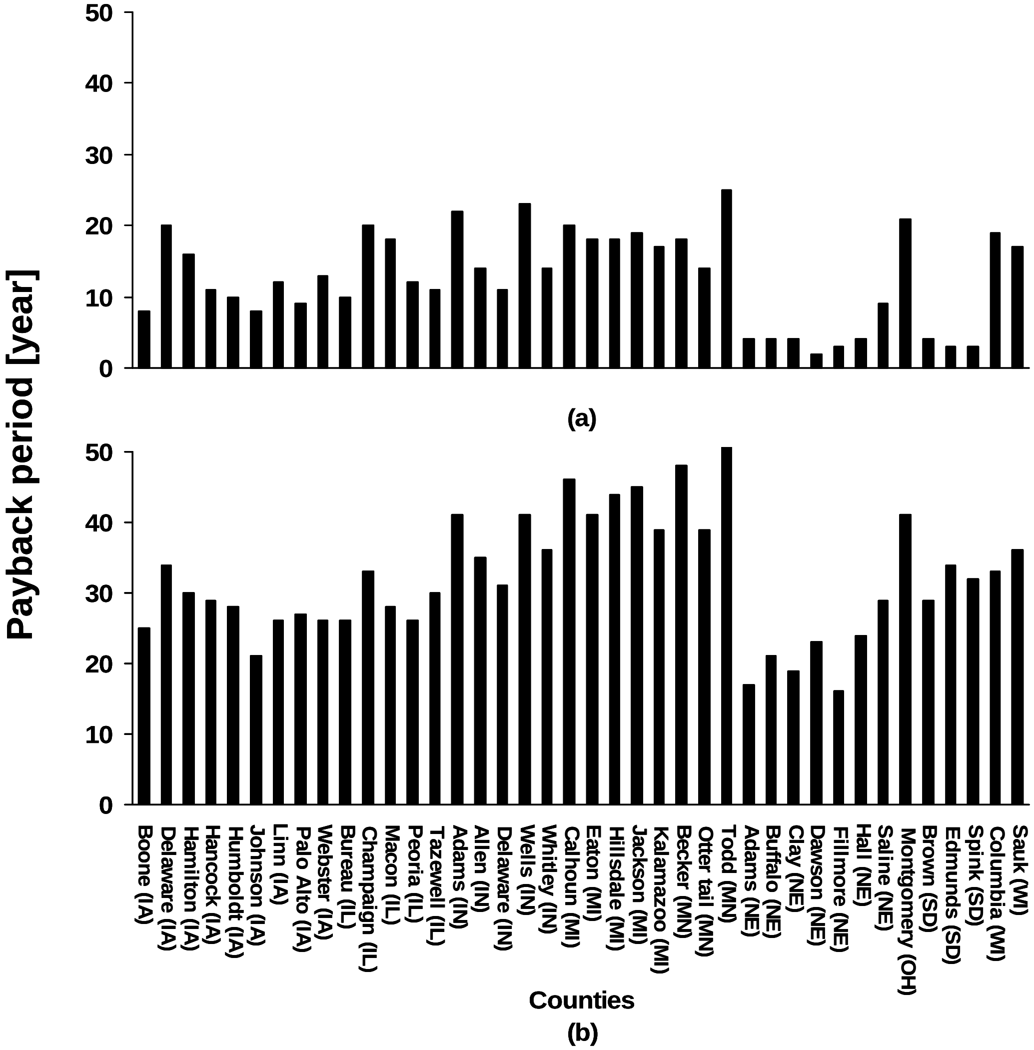

Figure S18. Payback periods in the reference case: (a) grassland conversion case; (b) forest conversion case

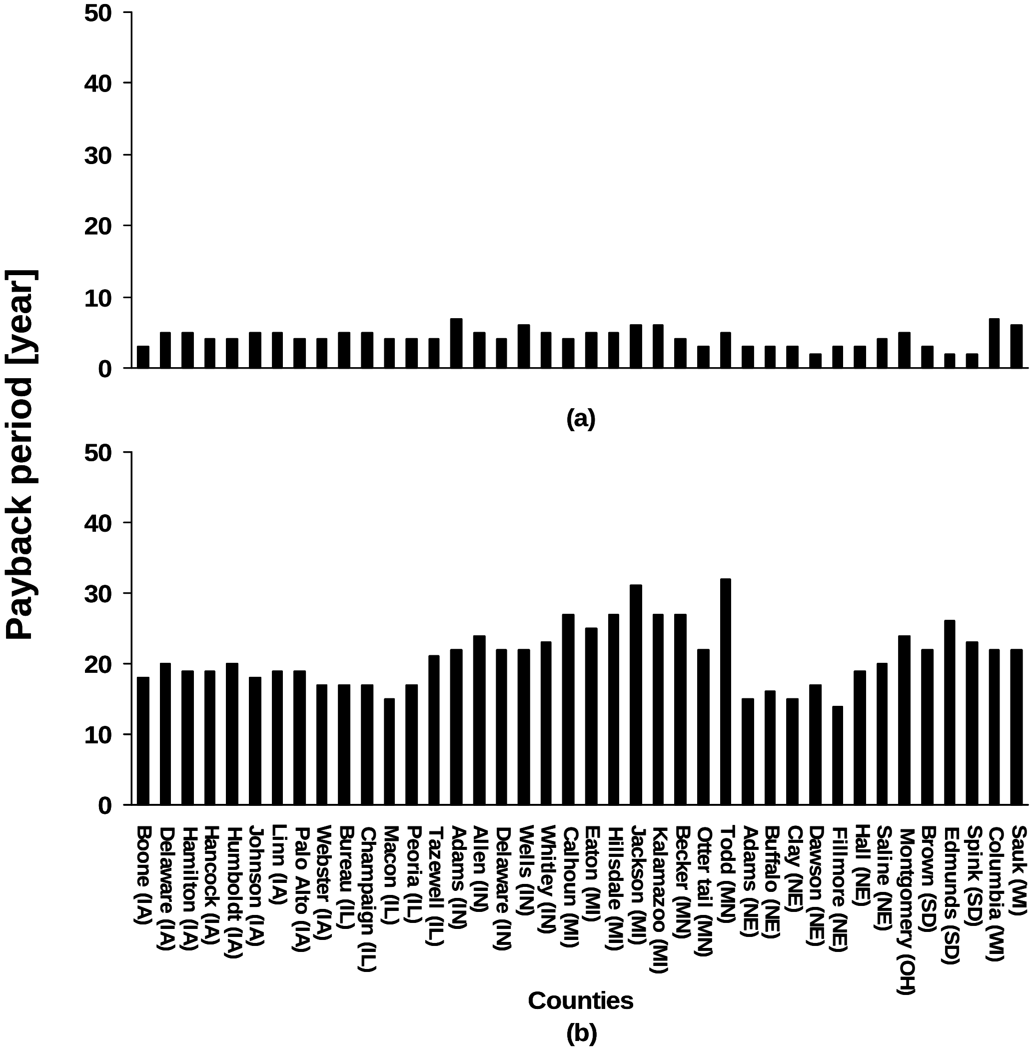

Figure S19. Payback periods in scenario A: (a) grassland conversion case; (b) forest conversion case

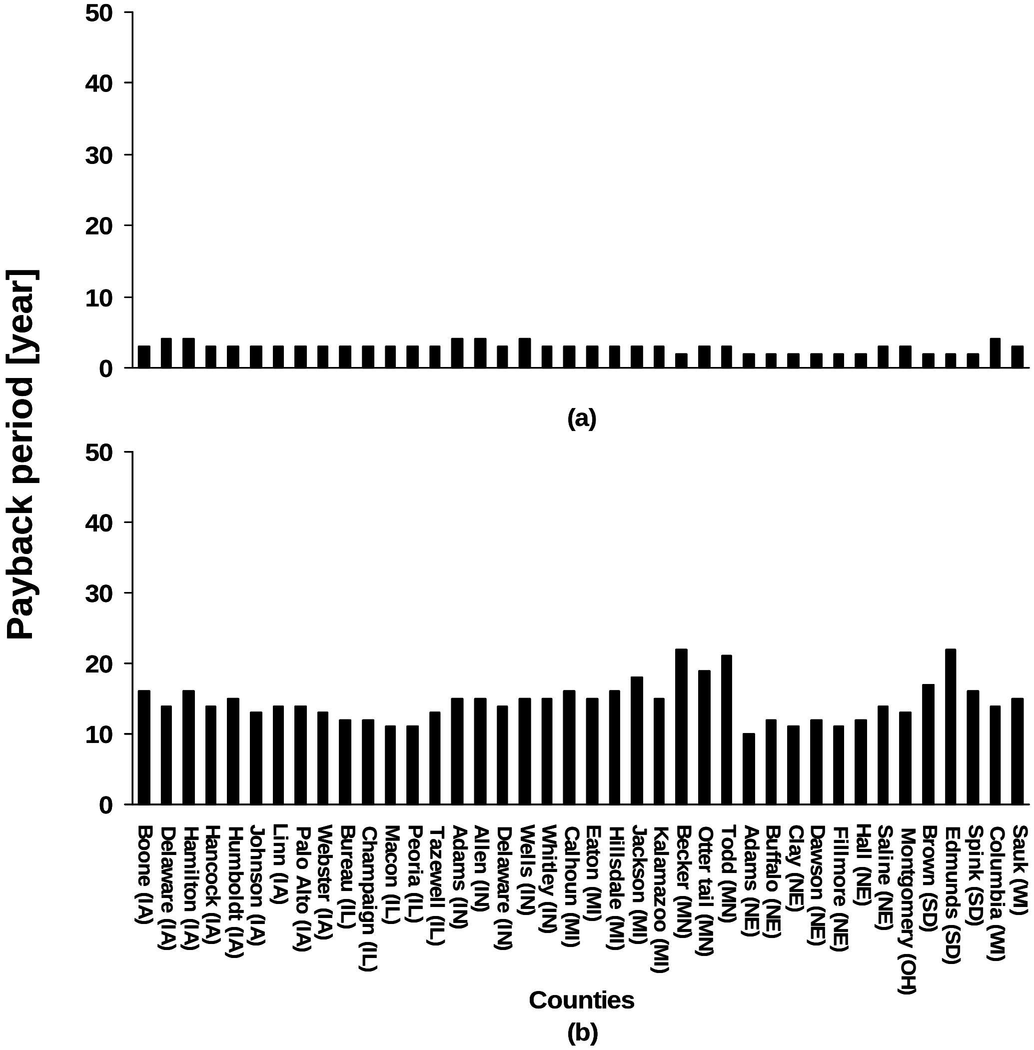

Figure S20. Payback periods in scenario B: (a) grassland conversion case; (b) forest conversion case

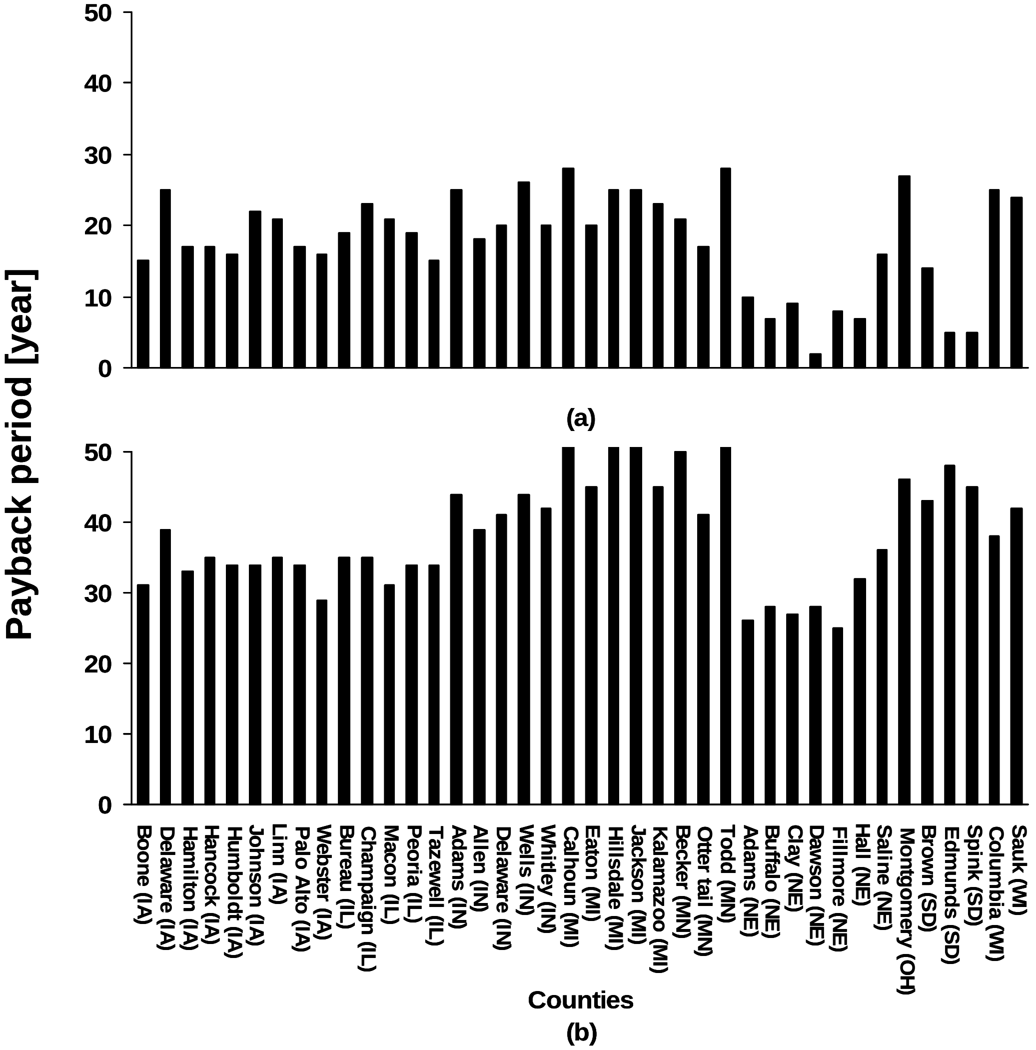

Figure S21. Payback periods in scenario C: (a) grassland conversion case; (b) forest conversion case

Scenario and sensitivity analyses

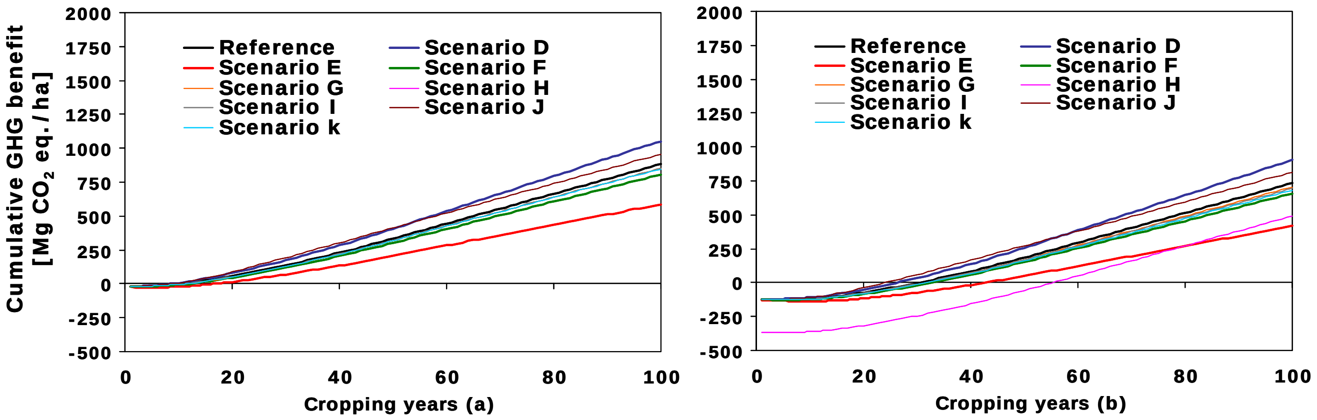

Figure S22. Scenario and sensitivity analyses

Table S2. Cumulative GHG benefits and payback period in scenario and sensitivity analyses

	Cumulative GHG benefits over 100 years [Mg of CO_2 equivalent per hectare]		Payback period [years]	
	Grassland case	Forest case	Grassland case	Forest case
Reference	882	734	12	31
Scenario A	1019	861	4	20
Scenario B	1327	1185	3	14
Scenario C	806	664	18	37
Scenario D	1053	905	9	27
Scenario E	586	418	17	43
Scenario F	807	658	13	33
Scenario G	851	704	12	32
Scenario H	-	492	-	56
Scenario I	851	693	12	32
Scenario J	955	814	9	24
Scenario k	848	680	12	32

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