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Opportunities for Nebraska in Future Carbon Markets: Final Technical Report for NCESR Project 3-#303

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1. Executive summary:

This study was funded to explore potential opportunities for Nebraska in future carbon markets, most explicitly those opportunities related to the possibility of replacing fossil fuels with biomass at Nebraska corn ethanol plants.

The most direct and significant finding is that biomass-fired CHP (combined heat and power) technology is not economically viable for Nebraska corn ethanol plants under current conditions. We estimate in the study that corn stover price would have to be at least $50 per ton of dry matter for the requisite amounts to be delivered to any of the three ethanol plant locations considered (Adams, Norfolk and Wood River). At this price, adoption of CHP would reduce ethanol plant fuel expenditures from about $0.16 per gallon for fossil fuels to about $0.10 per gallon for corn stover, and in addition could add nearly $0.04 per gallon in receipts from sale of surplus electricity to the grid, for a net operating cost reduction of about $0.095 per gallon. However, retrofitting a plant for CHP would require large capital investments with an amortized cost of about $0.24 per gallon, substantially greater than the fuel savings.

Potential carbon markets could add only marginal improvements to the prospects for CHP feasibility, adding revenues of about $0.02 per gallon from carbon offsets and perhaps another $0.014 from renewable energy credits. This would bring net operating cost savings to about $0.13 per gallon, still far from paying for the $0.24 per gallon capital cost.

CHP technology could become feasible if the capital cost for retrofitting a plant were to fall by 50%, or if natural gas and electricity prices were to rise considerably - at least 60% relative to 2009 prices. Another consideration is the impact of BCAP, USDA's Biomass Crop Assistance Program. This program offers producers a matching payment for whatever price they receive for biomass from an authorized biomass-using facility. The practical effect of this would be to cut in half the price that biomass facilities must pay for delivered biomass, except that the matching payments are limited to two years. Ethanol plants would not be able to invest the capital for retrofitting to biomass based on lower prices for biomass that are limited to only two years, so BCAP will have little impact on CHP feasibility.

It is possible that CHP-based ethanol could have a higher market value because of a lower carbon footprint, in California or states that adopt similar policies. We have not made an estimate of this value, because current California regulations do not include soil carbon losses within the boundary of the LCA (life cycle analysis) for the carbon content of biofuels. Our estimates are that conversion to stover-fired CHP would reduce the GHG intensity of the ethanol by 13.3 $gCO_2e\ MJ^{-1}$. However, the reduction of Midwest corn ethanol's footprint by that amount would provide a fuel with a GHG reduction of only 11% relative to gasoline, which would result in a minimal carbon premium in California even if their regulations were changed to recognize it.

An important contribution of this project has been the estimation of supply curves for various amounts of corn stover or switchgrass to be delivered at one of the three delivery points in the study. Biomass in large quantities may be used for other purposes, such as for co-firing with coal in electrical generating plants, or as a feedstock for cellulosic ethanol. The relationship between delivered price and quantity is important information in the evaluation of any such project. One significant finding of the study is that corn stover price would need to be at least $50 per ton of dry matter to have small amounts of less than 100,000 tons per year delivered, or $55-$62 per ton to have a million tons per year delivered, depending on the location in Nebraska. A second significant finding is the lack of competitiveness of switchgrass as a source of biomass in the area of the study. Given current switchgrass technology, prices would have to be $70-$75 per ton of dry matter for delivery of 100,000 to one million tons per year.

The project conducted several background studies to be able to address the above issues, results of which are summarized in the report. We reviewed the history and status of climate change initiatives in the U.S. and internationally, from which we were able to identify carbon credits as possible benefits in the future, and renewable energy credits and BCAP benefits available currently and the near future. We also reviewed and summarized the literature on ethanol's carbon footprint attributable to Indirect Land Use Change (ILUC), and though we did not attempt any original research on this issue, a thesis study was in progress at the close of the project examining the potential effects of corn stover revenues on the expansion of cropland into pasture and hay lands in Nebraska. Finally, we examined the relationships between prices of energy sources in Nebraska (natural gas, electricity, and diesel) to aid in understanding how changing energy prices would affect financial feasibility of retrofitting to CHP.

Delivered Products

Presentations :

"Environmental Efficiency among Corn Ethanol Plants" (Perrin, Sesmero & Fulginiti), at Purdue University, Michigan State University, and the annual meetings of the ***Am Agr and Appl Econ Association***, July, 2010.

"An Implementable Index of Sustainability and Assessment of Energy Policy " (Sesmero & Fulginiti), at Purdue University, U. of Wisconsin, the Hearland Environmental Resource Workshop (U. of Illinois), and the annual meetings of the ***Am Agr and Appl Econ Association***, Denver, CO, July, 2010.

"The Welfare Impact of Removing Biofuel Blender's Tax Credit Subsidy in United States" (Wamisho) at the annual meetings of the ***Am Agr and Appl Econ Association***, Denver, CO, July, 2010.

"Economic Efficiency of Ethanol Plants in the US North Central Region. " (Sesmero, Perrin & Fulginiti) at the annual meetings of the ***Am Agr and Appl Econ Association***, Denver, CO, July, 2010.

"Economic and Policy Issues" (Perrin and Fulginiti), UNL ***Summer Institute on Climate Change***, Lincoln, May 11-13, 2010.

"Climate Change Policy: The Waxman-Markey Bill" (Alvarez), "Feasibility of Corn Stover for CHP in Grain Ethanol Plants in Nebraska" (Sesmero), "Cost of Supplying

Biomass for Bioenergy" (Wamisho). Posters at the May, 2010, ***UNL Research Fair***.

"Energy and the Environment," (Perrin) UNL ***OLLI*** course "Economic Issues 2010," April 19, 2010.

"Uncertainty in Indirect Land Use Change Emissions in the Life Cycle of Biofuels: Implications for Legislation" (Liska) ***Biomass 2010 Conference***, Washington DC, March 30, 2010.

"Life Cycle Greenhouse Gas Emissions from Biofuels: Variability, Uncertainty, and Steps Toward Accurate Regulation" (Liska), ***Governors' Agriculture, Energy, and Sustainability Roundtable***, Washington, D.C., Jan. 28, 2010

"Feasibility of Corn Stover as Fuel for Combined Head and Power (CHP) in Grain Ethanol Plants in Nebraska," (Perrin, Liska, Sesmero, Fulginiti), ***North Central Bioeconomy Consortium***, "Growing the Bioeconomy", Dec 1, 2009.

"Corn Ethanol – Viable?" at the meeting of the ***Nebraska Ethanol Board***, Nov 5, 2009.

"Magnitude and Variability in Emissions Savings in the Corn-Ethanol Life Cycle from Feeding Co-Products To Livestock," (Liska, et al), ***CRC Workshop on Life Cycle Analysis of Biofuels***, Argonne National Laboratory, Chicago , IL., Oct. 21, 2009

"Life Cycle Emissions Standards for Biofuels: Transparency, Relevance, and Uncertainties," (Liska et al) 238^{th} ***American Chemical Society National Meeting***, Washington, DC, Aug. 18, 2009.

Publications:

Sesmero, J., R. Perrin and L. Fulginiti. "Environmental Efficiency among Corn Ethanol Plants", under review at *Biomass and Bioenergy* .

Liska, A.J. (submitted) "Eight Principles of Uncertainty for Life Cycle Assessment of Biofuel Systems." Chapter 22, IN: *Biofuels: Environmental Implications and Impacts,* Brouder et al. (eds.), Cambridge University Press.

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Perrin, R.K. 2009. "Ethanol: Carbon Footprint a Problem?" *Nebraska Farmer*, Feb. 2009.

2. Feasibility of biomass-fired CHP technology for Nebraska ethanol plants (R. Perrin, J. Sesmero, A. Liska, L. Fulginiti)

This chapter analyzes ethanol plants' potential willingness to pay for biomass to fuel CHP technology, and compares that willingness to pay with the estimated cost of supplying biomass. This comparison is based on the potential technical coefficients and prices involved in converting a dry-mill ethanol plant to combined heat and power (CHP), fueled by corn stover. This conversion would substitute expenditures on biomass for current expenditures on electricity and natural gas, but would also require a large capital expenditure. Because the conversion substitutes biomass fuel for fossil fuel, sale of carbon credits might provide additional revenue if and when carbon markets develop. The profitability of conversion to biomass will depend on energy prices, the value of carbon incentives, and the capital cost of conversion, which the analysis will demonstrate.

The focus of this analysis is the "willingness to pay" (WTP) by an ethanol plant for biomass. WTP is defined as the *maximum* price that could be paid for stover while still being able to break even from the conversion to CHP. An ethanol plant would just break even from conversion if stover were priced at the plant's WTP, and while the plant would have no incentive to convert at that price, the WTP provides an upper boundary on the stover price that would make conversion profitable. To estimate WTP, we evaluate the savings from eliminating electricity and natural gas purchases, add carbon market benefits, then subtract from that the capital cost of conversion. This net benefit is the maximum available to spend on stover, and it defines WTP.

2.1 Technology and capital costs for converting ethanol plants to CHP

The majority of corn ethanol production in the U.S. utilize natural gas and electricity as energy sources in dry mill ethanol plants. Tiffany, et al, (2009) have evaluated the capital cost of adding a fluidized bed combustion process to a natural gas powered dry-grind corn ethanol plant. They utilized USDA's ethanol plant version of the Aspen Plus process simulation model, augmented by expertise from a consulting engineering firm. Plant sizes considered were 50 million gallons per year (mgy) and 100 mgy. They considered technology that was scaled alternatively to meet just the needs of the plant for process heat, the needs for combined heat and power (CHP), or the potential for providing CHP plus surplus electricity to the grid. We examine the latter in this study because we calculated it to be the least-cost technology for Nebraska conditions. Though we do not consider it here, they also analyzed CHP technology that could combust distillers grains and solubles (byproducts of ethanol production) in addition to biomass.

Tiffany, et al, estimated both the extra cost of CHP installation in new construction and the cost of retrofitting an existing natural gas fired plant. The present study is primarily concerned with the cost of retrofitting existing plants. This because most of the capacity to meet the U.S. RFS2 standard (15 billion gallons per year) is either already in production or under construction, leaving little opportunity for including CHP in new construction. We thus use the Tiffany, et al, estimate the capital cost for CHP-scale technology in a 50 mgy plant to be $90 million, or $1.79 per gallon of capacity. For a 100 mgy plant their estimate is $146 million, or $1.46 per gallon of capacity. (Comparable cost estimates for adding CHP to new construction are $1.19/gal and $0.96/gal, respectively, or 34% less than the cost for retrofitting.)

Capital costs are reduced by a 10% CHP investment tax credit plus a 7.5% "Advanced Energy Manufacturing Tax Credit." (The maximum credit attainable by a plant is 30%. But because the plant is supposed to enter a competition and the credit obtained will depend on its place in a final ranking, we have assumed an expected return equal to one fourth of the credit.) Thus we estimate the capital cost per gallon for a 100 mgy plant at $1.20/gal. (Note that this cost is quite high relative to recent construction costs of $1.50-$2.25 per gallon of nameplate capacity.) We annualize capital investment by amortizing over 10 years at 15% interest, which yields a capital recovery factor of 0.199, which results in a prorated capital cost of $0.24 per gallon of capacity.

2.2 Current economic feasibility of adopting CHP technology

The maximum price that an ethanol plant could pay for a ton of biomass depends on whether or not CHP technology has already been installed. Once this CHP technology is installed, the plant is able to use either biomass or traditional natural gas and electricity for plant operations, whichever is cheaper. However, the primary emphasis of this study is the amount plants would be willing to pay after considering both capital costs and operating costs, as this will determine the feasibility of adoption. A summary of cost estimates for the two technologies is presented in Table 2.1.

Energy requirements for standard technology from a survey of recent vintage dry-grind ethanol plants have been reported by Perrin, et al, (2009, Table 6). Their results indicated that plants selling byproduct as modified wet distillers grains and solubles (MWDGS), such as is typical of plants in Nebraska, use of 0.57 kWh of electricity and 0.0202 MMBtu of natural gas per gallon of ethanol produced, for a total energy requirement of 0.0221 MMBtu. Using the same simulation analysis as reported in Tiffany, et al, De Kam, et al, (2009, Table 13) calculate biomass requirement for the CHP technology considered here to be 5.4 lbs of stover DM per gallon of ethanol, for a total energy requirement of 0.0462 MMBtu per gallon. However, their simulation model overestimates the energy requirement of a standard natural gas fired plant at 0.0322 MMBtu/gal, 45% higher than surveyed plants used. On the recommendation of Vance Morey, one of the authors of these reports, we therefore reduce their estimate of CHP requirement from 5.4 lbs of stover to 3.71 lbs per gallon to bring their results closer to observed plant performance.

Table 2.1. Energy budgets for standard and CHP ethanol plants

	Standard Technology			CHP technology		
Operating costs:	Quantity	Price per unit	Cost per gallon	Quantity	Price per unit	Cost per gal
Electricity (kWh/gal)[a]	0.57	0.058	0.033			
Natural Gas (MMBTU/gal)[b]	0.02	6.057	0.122			
Stover (lb DM/gal)[c]				3.71	0.027	0.098
Sale of electricity to the grid KWh/gal [g]				1.69	0.022	-0.037
CHP capital cost per gallon[d]:				1.202	0.199	0.240
Total energy related costs per gallon			0.155			0.301
Additional CHP benefits:						
Carbon credits (tons/gal)[e]				0.0016	13	0.021
Renewable energy credits (kWh/gal)[f]				0.710	0.02	0.014
Total additional benefits						0.035
Net comparable energy costs			**0.155**			**0.266**

[a] Requirements from Perrin, et al (2009), 2009 prices from http://www.eia.doe.gov/cneaf/electricity/epm/table5_3.html
[b] Requirements from Perrin, et al (2009), average 2009 prices from http://tonto.eia.doe.gov/dnav/ng/hist/n3035ne3m.htm
[c] Requirement estimated from De Kam, et al (2009), price is average from three delivery points in NE (Chapter 3)
[d] Source: as derived in the text
[e] EPA estimate of CO2 price under Waxman-Markey bill
[f] Source: price from http://apps3.eere.energy.gov/greenpower/markets/certificates.shtml?page=1
[g] Representative avoided cost data for 2009-2010 from Nebraska Public Power District

In the budget of Table 2.1 we price stover at $53/t DM (about $45/t field wt), which is the average supply price we calculate in Ch 3 as being necessary to supply three typical ethanol plants in Nebraska. Ethanol production costs other than energy costs will not vary between CHP and standard technologies, so they are ignored here. At 2009 prices, CHP fuel costs alone are $.098/gal, and only $0.061/gal after deducting sales of electricity to the grid, compared to $0.155 for standard fossil-based fuels. A plant with CHP installed would clearly choose biomass rather than fossil-based fuels. But when the extra $0.24/gal capital cost is included, total fuel cost per gallon becomes about $0.145/gal more expensive with CHP, so there is no incentive at present for existing natural gas-fired plants to retrofit with CHP technology. For plants not yet constructed, the capital cost for adding CHP is about one third lower, but even in this case the total CHP fuel cost would be about $0.221/gal, compared with standard technology at a comparable fuel cost of $0.155/gal.

The possibility of carbon markets in the future may provide two opportunities for additional benefits from CHP, as discussed in Ch. 5. First is the possibility of selling carbon credits on a potential cap-and-trade market. The California Air Resources Board (2009) has estimated that CHP technology would reduce carbon emissions from electricity by 0.44 t CO2e/MWh, and emissions from natural gas by 0.05 t CO2e/MMBTU. These rates translate to carbon credits of 0.0016 t CO2e/gal of ethanol produced. EPA has estimated that the price of carbon trading under the initial years of the Waxman-Markey bill would have been about $13/ t CO2e, which would provide a credit of about $0.021/gal of ethanol.

The second possible "green" revenue could be sales of renewable energy credits (RECs). As described in Ch. 5, an REC is generated when an entity generates a MWh of energy from renewable sources such as biofuels. Requirements for a unit of electricity to qualify for REC status vary with the entity that establishes the REC, so RECs are not a homogeneous commodity. Nonetheless, specifications have become sufficiently coded and documented that RECs may be sold through such market clearing entities as APX (http://www.apx.com/environmental/renewable-energy-market-infrastructure.asp) . Purchasers of RECs may be electric utilities that are required to meet renewable energy portfolio standards, or any other entity with a motive to establish clean energy use by purchasing REC offsets. Renewable energy portfolio standards have been enacted by thirty states acting either alone or in consortiums. Nebraska does not participate in any such consortium, but electricity generated by Nebraska facilities may qualify for RECs in some of these jurisdictions, and it is possible that future federal or state initiatives will place Nebraska under such regulations. Prices of RECs vary across markets and through time, but retail prices currently average close to $0.02/kWh.

The total of these potential green credits is about $0.035/gal of ethanol, still leaving the full CHP fuel costs about $0.11/gal higher than fossil fuel prices, though only about $0.08/gal higher under capital cost for new construction, rather than the cost of retrofitting an existing plant.

2.3 Willingness to pay for stover and CHP retrofits as energy prices rise

The budget comparisons above show that adoption of CHP power in ethanol plants is not viable under current economic conditions. An important issue is how that viability changes under alternative conditions, most importantly, under alternative energy prices. We examine this question by considering the maximum value ("willingness to pay") of stover and CHP technology as energy prices rise.

Based on inputs usage and prices shown in Table 2.1 the energy-related cost per gallon of producing ethanol under standard and CHP technologies can be expressed as functions of energy prices:

(2.1) $$\begin{aligned} C^{standard} &= 0.57P^{electricity} + 0.020P^{naturalgas} \quad ; \\ C^{CHP} &= 3.71P^{stover} - 1.69P^{gridsales} + 0.199C^{cap} - 0.0016P^{carbon} - 0.710P^{REC} \end{aligned}$$

CHP technology thus becomes viable when:

(2.2) $$\begin{aligned} &\left(3.71P^{stover} - 1.69P^{gridsales} + 0.199C^{cap} - 0.0016P^{carbon} - 0.710P^{REC}\right) \\ &\qquad \leq \left(0.57P^{electricity} + 0.020P^{naturalgas}\right) \end{aligned}$$

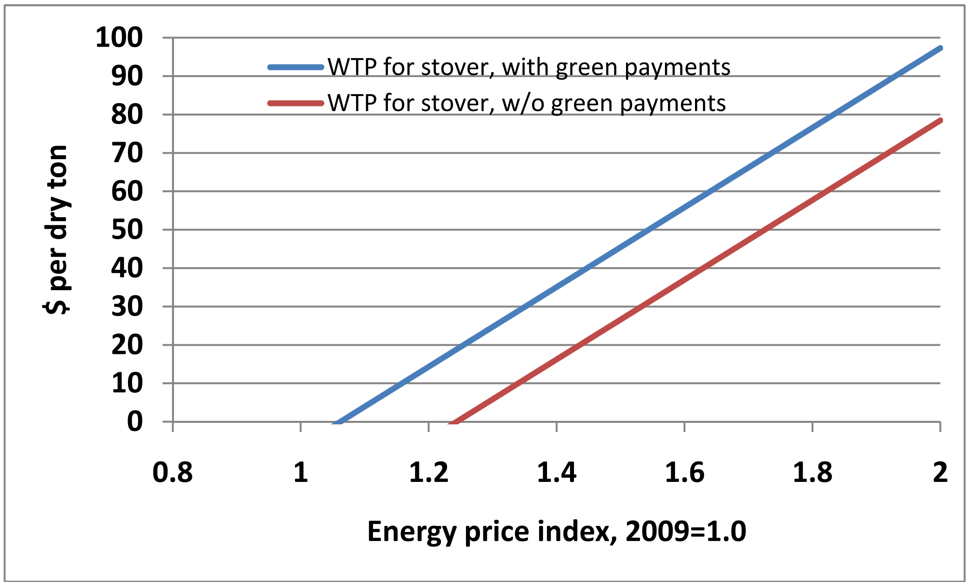
By manipulating this equation, we identify the prices for stover and for CHP capital cost that just make CHP viable, given current prices for other commodities. These are the maximum prices that an ethanol plant could pay, so we identify them as the plant's willingness to pay for stover or CHP technology.

By solving the above equation for P^{stover}, we identify the maximum price of stover at which CHP technology is viable, for given prices of other inputs. We group together the energy prices as (0.57 $P^{electricity}$+0.020$P^{natural\ gas}$ + 1.69$P^{grid\ sales}$), and multiply this sub-cost times an index of energy prices that has a value 1.0 for the 2009 prices, which are identified in the budget. We assume that all these energy prices rise or fall at the same rate, reflected by the value of the energy price index. The resulting equation identifies the willingness to pay for a pound of stover dry matter as a function of the index of energy prices.

(2.3) $$\begin{aligned} P^{stover} \leq &\left(0.154P^{electricity} + 0.00543P^{naturalgas} + 0.456P^{gridsales}\right)I^{energy} \\ &- 0.0537C^{cap} + 0.000431P^{carbon} + 0.191P^{REC} \end{aligned}$$

In Fig 1.1, we modify this equation in two ways and plot stover price against the energy price index. First we multiply the resulting price by 2000 to graph the willingness to pay in dollars per dry ton, and second, we set "green" prices, i.e., prices for carbon and RECs, equal to zero to illustrate their effect on willingness to pay.

Figure 2.1. Willingness to pay for biomass as a function of energy prices



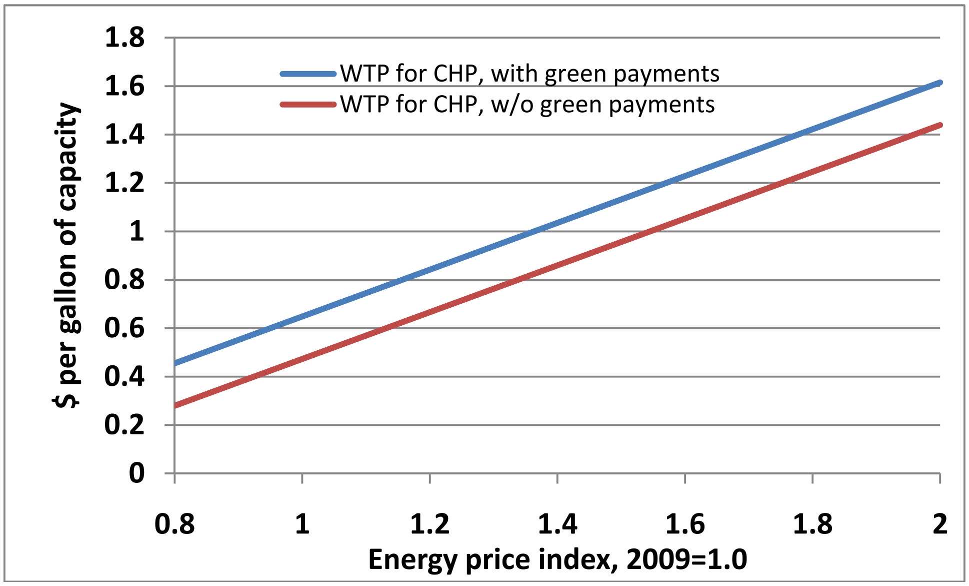
The graph demonstrates that at 2009 energy prices, plants would not be willing to pay anything at all for biomass. If energy prices increased by as little as 20% over 2009 levels, plants could pay up to $15 per dry ton and still be able to cover the capital cost with green payments included, and if energy prices doubled, plants could pay nearly $100 per ton and still find adoption profitable. The addition of credits for carbon and RECs enables plants to pay an additional $20 per ton of biomass, the vertical distance between the two lines.

Next we consider ethanol plants' ability to pay capital costs for retrofitting an existing 100 mgy plant with fluidized bed combustion technology to accommodate biomass fuels. Solving equation (2.2) for C^{cap} , we identify the maximum capital investment cost that plants could pay per gallon of ethanol capacity:

$$C^{cap} \leq \left(2.861P^{electricity} + 0.101P^{naturalgas} + 8.498P^{gridsales}\right)I^{energy} - 18.627P^{stover} + 0.00803P^{carbon} + 3.563P^{REC} \quad (2.4)$$

The capital investment cost estimate in our budget is $1.20 per gallon of ethanol capacity for a 100mgy plant. As Figure 2.2 shows, at current prices plants could afford to pay only half that, about $0.60 per gallon of capacity, or even $0.45 if green payments are not included. The current retrofit investment cost of $1.20 would not be feasible unless energy prices energy prices were to rise at least 60%, or about 80% without green payments.

Figure 2.2. Willingness to pay for CHP installation as a function of energy prices



As previously noted, the capital cost of retrofitting a smaller, 50mgy plant would be about 25% higher than for a 100mgy plant, or about $1.48 per gallon of capacity. Adoption by such firms would not be feasible at prices below 180% of 2009 prices, or if green payments were unavailable at prices below 200% of 2009.

Conversely, we noted that the investment cost to install CHP technology in a new 100mgy plant would be about 1/3 lower than for retrofitting, or about $0.80 per gallon of capacity. In this case, CHP would become feasible at energy prices only 20-30% above 2009, depending on whether or not green payments were available.

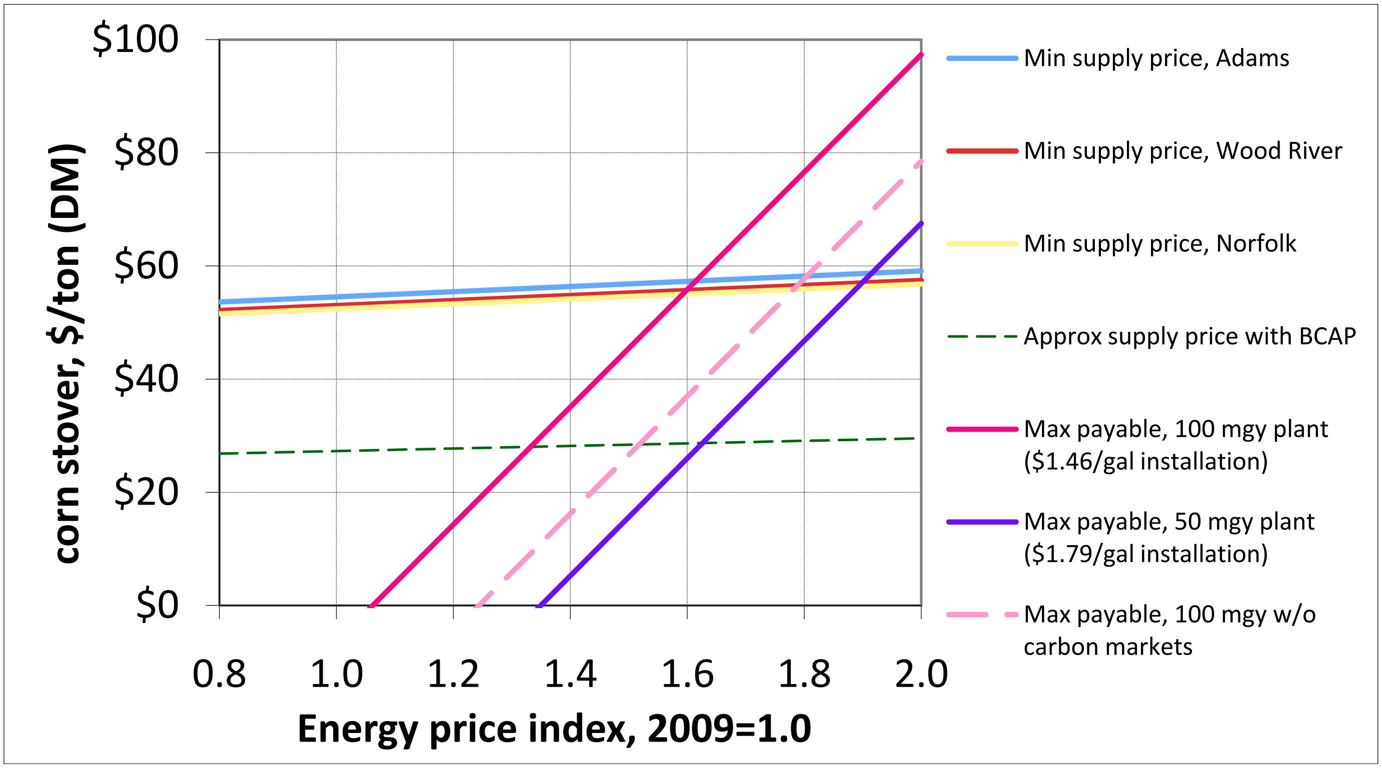
2.4. Energy prices and the viability of biomass CHP

Figure 2.3 illustrates individual plants' maximum willingness (ability) to pay for stover as energy prices rise. Because stover supply utilizes diesel fuel, the price necessary to bring forth an adequate supply of stover to fuel a plant will also rise with energy prices. As we have seen before, the three supply curves for the three areas lie close to one another, but the same is not true for the "maximum payable" curves.

The Wood River plant, with capacity of 110 mgy (slightly more than the 100mgy plant illustrated) would be the first to be able to adopt CHP because of the economies of scale realized in reduced retrofit costs. This plant would be able to pay $30 per ton more than a 50 mgy plant, the size of the plant at Adams. (The Norfolk plant with its 40 mgy capacity would be able to pay slightly less than the 50 mgy plant shown, but the

Tiffany and Morey analysis only provides us with investment cost estimates for 50 and 100 mgy plants.)

Figure 2.3. Breakeven energy prices for the adoption of biomass CHP at three corn ethanol plants in Nebraska



Even so, Figure 2.3 indicates that the Wood River plant would not find it feasible to adopt unless energy prices were to increase at least 60% over 2009 levels. At that point, the savings in fossil fuel costs would be adequate to pay for both the CHP capital cost and the $57 per ton for corn stover. Without carbon market payments (the dashed willingness to pay line), energy prices would have to rise to 80% above 2009 to make conversion feasible. The vertical distance between the two lines just mentioned, about $33 per ton, indicates the additional value that carbon markets would confer onto corn stover. The Adams and Wood River plants, given their smaller size, would not be able to adopt unless energy prices rise to about 90% above 2009 levels.

The dashed horizontal line indicates the potential impact of USDA's Biomass Crop Assistance Program (BCAP). This program (see Ch 5) offers to match prices producers receive for qualified biomass crops, dollar for dollar. If this subsidy were permanent, its effect would be to drop by half the price that biomass purchasers would have to pay, as indicated by the dashed line. This would make CHP more attractive, with adoption being profitable when energy prices rise only by 30% (Wood River) to 60% (Norfolk). However, the BCAP legislation limits matching payments to only two years. The capital investment to retrofit must be amortized over 10 years or so to become reasonable, so a low price for biomass for just two years would not provide adequate incentive for adoption under any circumstances. For this reason it is hard to imagine that the current BCAP will have any impact on CHP adoption.

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3. Biomass supply costs at three delivery points in Nebraska (R. Perrin, J. Sesmero, K. Wamisho and D. Bacha)

3.1 Introduction

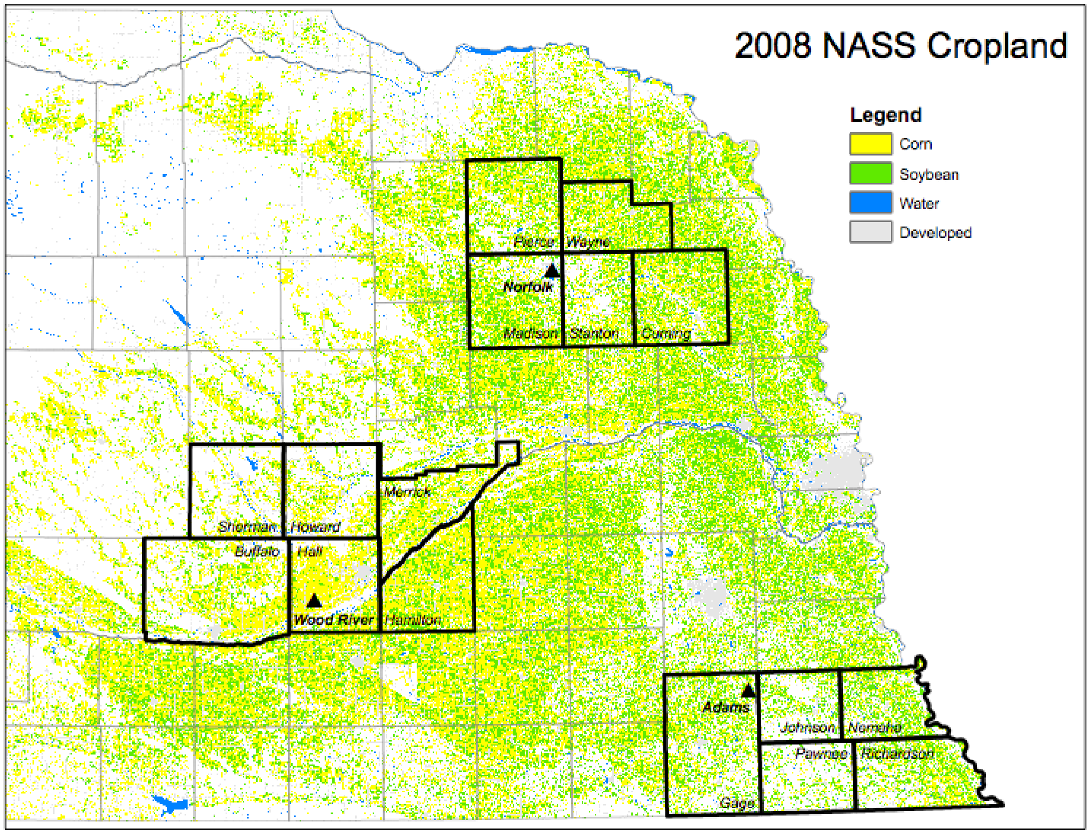
Crop residues such as corn stover and dedicated biomass crops such as switchgrass are potential substitutes for fossil fuels, either as direct combustion materials or after conversion to liquid fuels. Costs for collection, transportation and storage per unit of energy from these sources of biomass can be quite high because of the low energy density of the material and low density of available crop acres in a region. These costs can rise considerably with increases in the quantity supplied to a given delivery point. Research on densification technology may ultimately reduce these costs, but meanwhile, investment decisions by potential biomass users and producers must be based on current technologies. The objective of the present study is to evaluate the current-technology supply curves for delivery of various amounts of crop biomass to three delivery points in different agro-ecological zones in Nebraska.

3.2 Methods

Nebraska delivery points considered in this study are at the towns of Adams, Wood River and Norfolk (see Figure 3.1). The areas differ in cropping density and irrigation. In the vicinity of Wood River (Buffalo, Hall, Howard, Sherman, Hamilton and Merrick counties) most corn production is irrigated, while near Adams (Gage, Johnson, Nemaha, Pawnee and Richardson counties) very little is irrigated, and in the area around Norfolk (Cuming, Madison, Pierce, Stanton and Wayne counties) about one-third of crop acres are irrigated. In this study we use the crop characteristics of the designated counties to estimate supply conditions, but the biomass supply areas themselves are assumed to be circular around the delivery point.

The quantity of biomass required at a delivered point depends upon the nature and size of the facility at that point. For example, a very large cellulosic ethanol plant with 100 million gallon per year capacity would require about 1.25 million tons of biomass per year, whereas a corn ethanol plant of the same capacity using biomass for combined heat and power (CHP) would require only about 0.19 million tons. A corn ethanol plant is located at each of the delivery points in this study, providing a potential market for biomass either as combustion fuel for CHP technology or for future plant expansion or conversion to produce cellulosic ethanol. Conditions for other delivery points in the eastern half of Nebraska would be similar to one of the three regions we study here, so the supply curves estimated here are relevant to co-firing of coal-based electrical generating plants or other facilities in the general area.

Figure 3.1. Delivery points and counties for characterization of crop patterns



Biomass availability

The primary source of biomass currently available in these areas is corn stover, but switchgrass could be planted on less productive lands currently allocated to grass hay or pasture. In our spatial calculations, we assume that the distribution of crop acreages is uniform within each of the three areas. Above-ground corn stover production in each region is estimated at one-half of the average grain production (dry matter basis) in the area during 2006, 2007 and 2008. The harvesting strategy considered in this study is the removal of 50% of stover on 50% of corn acres, for an average harvest of 25% of available stover biomass. This harvest rate may be either higher or lower than the socially optimal rate based on productivity, soil conservation and soil carbon flux considerations, but it has generally been considered to be an environmentally feasible rate in the sense of keeping soil erosion from wind and water below the estimated soil loss tolerance.[1] Moreover, studies of the optimal harvest rate including productivity and environmental considerations are not available.

Much less is known about potential production of switchgrass biomass, because NASS statistics are not available for the crop. Instead, for average yield we use the average harvest results obtained in recent research on the commercial scale switchgrass fields of ten collaborating producers in the Great Plains over the years 2000-2005 (Perrin, et al., 2008). Those yields, following the establishment year, were approximately 3 tons of dry matter per acre. We calculate the potential area of switchgrass production in each region as the total acres of cropland that is either idle, used only for pasture, or used for hay production (other than alfalfa), plus land in permanent pastures (NASS, 2007 Census of Agriculture). For spatial calculations, we assume a uniform distribution of this acreage across the area, as we also assume for corn stover.

Calculation of aggregate supply functions

Costs of delivery of biomass to a given point consist of production costs at the farm plus transportation costs. Given our assumption that acreage, yield and harvest practices are homogeneously distributed around the delivery point, additional deliveries come from an expanding circle around the delivery point, with transportation cost determined by the radial distance to the point of production, following the general approach of Gallagher, et al., (2003). Given these assumptions, total cost of delivering q_k^i dry tons of feedstock *i* (*i* = stover, switchgrass) to point *k* (*k* = Adams, Wood River, Norfolk) can be expressed as[2]

$$TC_k^i = a_k^i q_k^i + bq_k^i + \frac{2c}{3\sqrt{\pi d_k^i}}\left(q_k^i\right)^{3/2} \tag{3.1}$$

where a_k^i represents on-farm costs per ton, *b* represents loading, unloading and stacking costs per ton of any feedstock, *c* represents transportation cost per mile for any feedstock, and d_k^i represents harvest density in tons per square mile.

Based on this expression the marginal cost of quantities delivered (*i.e.,* the inverse supply function) can be expressed as

$$MC_k^i = a_k^i + b + \frac{c}{\sqrt{\pi d_k^i}}\sqrt{q_k^i} \ . \tag{3.2}$$

To obtain the supply function for the quantity of feedstock *i* in region *k*, we set price at marginal cost and solve this equation for quantity delivered. This supply function is thus quadratic in prices:

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[1] EC88-116 Universal Soil Loss Equation: A Handbook for Nebraska Producers[41], A.J. Jones, D. Walters, W.G. Hance, Elbert C. Dickey, and J.R. Culver.

[2] Quantity harvested within radius R is $q=\pi dR^2$. Cost of transporting production at just the radius r is $d(2\pi r)rc$. Integrating from r=0 to r=R, $C(R)=(2/3)cd\pi R^3$. Substituting q for R, $C(q) = (2/3)c(d\pi)^{-1/2}q^{3/2}$.

$$q_k^i = \begin{cases} \frac{\pi d_k^i}{c^2}\left[p^2 - 2(a_k^i + b)p + \left(a_k^i + b\right)^2 \right], \text{ if } p > \left(a_k^i + b\right), \\ 0, \text{otherwise.} \end{cases}$$

(3.3)

The aggregate supply function for delivery of all biomass feedstocks to a given point is the horizontal sum of these individual feedstock supplies.

We estimate costs of production, harvesting and transportation of biomass based on operations required using conventional technology. Costs estimated for these operations are custom rates for the operations as reported from survey data in Nebraska (Jose, 2010), reported in Table 3.1.

Table 3.1. Most common custom rates for biomass harvest operations.

Operation	unit	Custom rate per unit	Gal diesel per unit[b]
Stalk shredding	acre	8.90	0.45
Stalk raking	acre	5.00	0.25
Swathing hay with crushing	acre	12.00	0.62
Baling, large round w/netwrap (1589 lbs switchgrass, 1335 lbs stover per bale)	bale	12.00	0.4
Moving bales to edge of field	bale	2.00	0.2
Hauling round bales (30,000 lb load)	loaded mile	3.50	0.125

[a] Source: Jose (2010)

[b] Source: Hanna (2001)

This method of estimating costs is in contrast to virtually all other biomass supply studies, which have used engineering cost approaches to estimate the cost of various operations. We isolate the fuel component of these costs by relying on engineering estimates of the amount of fuel required for each operation (Hannah, 2001), multiplied by current diesel price. This allows us to adjust estimated biomass supply costs for changes in the level of fuel prices.

3.3 Results

Of the costs identified in the section above, loading/stacking costs (b) and transportation costs (c) are common to both corn stover and switchgrass, because we assume that both feedstocks are handled in conventional large round bales. Given that we have no custom rate data for loading, unloading and stacking bales at the destination, we utilize the estimates of Kumar (2007, p. 1038) of \$1.61 t^{-1} for loading and \$2.13 t^{-1} for unloading and stacking, yielding the estimate b = \$3.74. We estimate the diesel fuel component for these operations at 0.1 gal t^{-1} .

We estimate transportation cost based on the reported custom rate (Table 3.1) of \$3.50 per loaded mile for semi-trailer trucks that hold 26 bales weighing 0.55 t (DM), or c = \$0.245 per ton mile. The diesel fuel component, based on 8 miles per gallon, is 0.0087 gallons per ton mile of dry matter. Remaining cost components are on-farm costs (a_k^i) and harvest density (d_k^i), which vary by source and region, as detailed next.

Corn stover: harvest densities and on-farm costs

The average stover harvest densities during 2006-2009, d_k^{stover}, around Adams, Wood River and Norfolk were 115, 299 and 214 tons of DM per square mile, as calculated in Table 3.2. Here we assume that stover yield equals corn grain yield, that moisture content of both grain and stover is 15%, and that half the stover is removed from half of the corn acreage each year.

Table 3.2. Stover harvest densities around three delivery points.

	units	Adams	Wood River	Norfolk
Avg corn density, 2006-08	ac mi^{-2}	150	290	240
Avg corn grain yield, 2006-08	bu ac^{-1}	129	173	150
DM stover/ac corn[1]	t DM ac^{-1}	3.07	4.12	3.57
Harvest density, d [2]	t DM mi^{-1}	115	299	214
Bales (0.567 t DM) per ac harvested	bales/ac	5.41	7.26	6.30

[1](Corn yield)*(0.028 t/bu)*(.85 DM)

[2](t DM ac^{-1})*(ac mi^{-1})/4

On-farm costs, a_k^{stover} , summarized in Table 3.3, are based on custom rates for various operations as reported in Table 3.1, and on harvest densities shown in Table 3.2. These operations use current commercial technology for large round bales, covered with bale wrap and moved to the edge of the field for later retrieval.

The appropriate rate of stover removal remains controversial, because the relationship between removal rate, soil conservation and future yields is not well understood. Varvel, et al. (2008) report that removal of 50% of corn stover in Nebraska results in a yield reduction of about 5%, while Moebius-Clune, et al. (2008) report a reduction of about 8% in New York. Blanco-Canqui, et al. (2006) report mixed results. Similarly, an earlier authoritative review by Wilhelm, et al. (2004) revealed that many experiments have showed no yield reduction from stover removal, and they concluded that the inconsistency of results is probably explained by differences in soil type, weather, tillage, etc. Walters (2009) and others have measured nutrients removed from the field with stover harvest, which are approximately 16 lbs of N and 1.8 lbs of elemental phosphorus, P, per ton of stover. Potash is also removed, but this nutrient is at present not limiting in most soils of the Great Plains. For this study we simply assume that harvesting only 25% of the stover with replacement of these nutrients would compensate for future yield losses. Current materials and application costs for these nutrients total $17.03.

Total on-farm costs for harvesting and collecting stover range from $43.43 per ton in the Wood River area to $45.36 per ton in the Adams area (Table 3.3).

Table 3.3. On-farm costs per ton of stover[a]

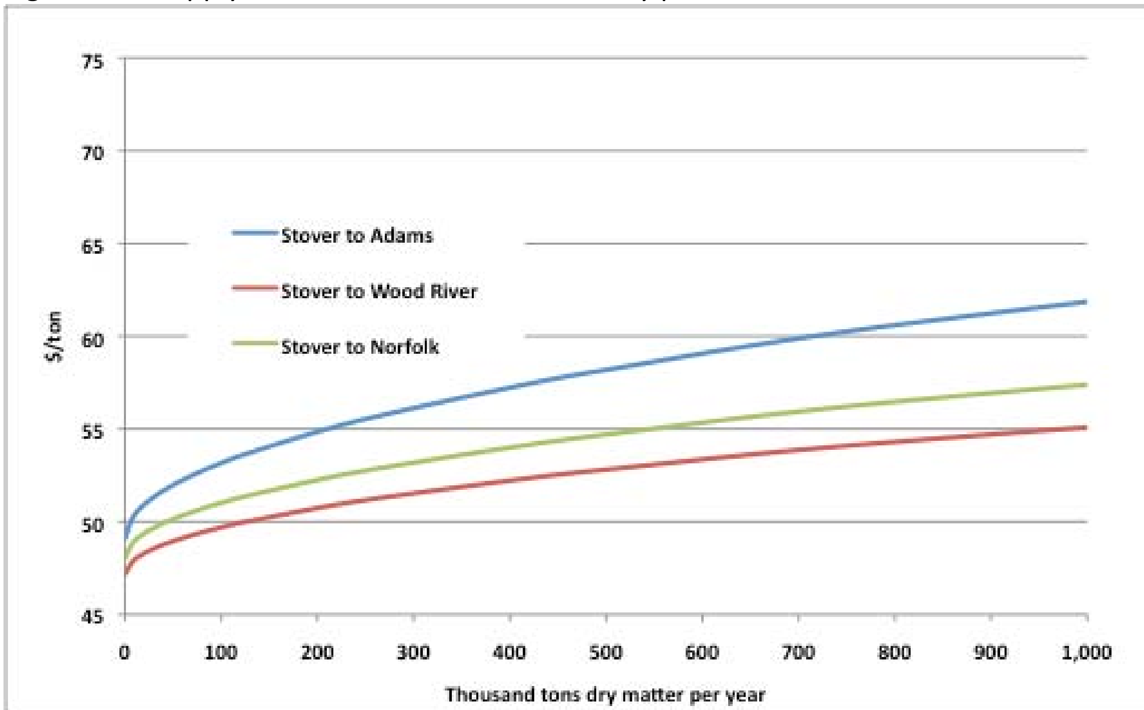
	Adams	Wood River	Norfolk
Stalk shredding	4.87	3.63	4.19
Raking	2.73	2.04	2.35
Baling, large round w/netwrap	17.77	17.77	17.77
Moving bales to edge of farm	2.96	2.96	2.96
Nutrient replacement[b]	$17.03	$17.03	$17.03
Total	45.36	43.43	44.30

[a] Calculated from tables 3.1 and 3.2

[b] 16 lbs N, 1.8 lbs P

Given our estimates of cost parameters described above, stover supply schedules calculated from equation (3.3) for the three delivery points are graphed in Figure 3.2. Harvest density is the primary factor distinguishing the levels of the three supply curves. Delivery of 1 million tons in the Adams area involves about $15 t^{-1} of transportation costs at the extensive margin (about 64 miles radius), whereas at Wood River, marginal transportation cost for the millionth ton (about 40 miles) is only about $10 t^{-1}. Note that biomass producers within the radius would receive some geographical rents, as the price they would receive would more than compensate for their lower transportation expense.

Figure 3.2. Supply of corn stover to three delivery points in the Great Plains



Switchgrass: harvest densities and on-farm costs

We assume that land around the delivery points available for conversion to switchgrass production includes permanent pastures and cropland that is either idle, used only for pasture, or used for hay production (other than alfalfa). This comprises from 25% of the area in the Adams region to 40% of the area around Wood River (Table 3.4). We estimate the average switchgrass yield after the establishment year to be 3 tons of dry matter per acre, the average yield obtained in ten on-farm, commercial scale trials in the Great Plains during 2001-2005 (Perrin, et al, 2008a, 2008b). The density of potential switchgrass harvest at this yield ranges from 460 to 794 t DM mi^{-1} (Table 3.4), two to four times greater than harvest densities of corn stover.

Table 3.4. Switchgrass harvest densities around three delivery points

	units	Adams	Wood River	Norfolk
Avg acreage density, 2006-08	ac mi^{-2}	172	265	153
d = harvest density	t DM mi^{-1}	516	794	460
Bales (0.675 t DM) per ac harvested	Bales ac^{-1}	4.4	4.4	4.4

Production costs for switchgrass in this region (Table 3.5) include land rent, (unnecessary for harvesting stover because the land is already committed to that crop) and an expected establishment cost of \$226.25 a^{-1} that includes an allowance for re-seeding, which is expected 25% of the time. We amortize this expense over an expected 10 years of production, using an 8% amortization rate (capital recovery factor = 0.15), resulting in an annualized establishment cost of \$33.94 a^{-1}.

Table 3.5. On-farm production costs of switchgrass for biomass

Operation	Cost of operation		Materials cost per acre [c]			Total cost per acre
	Custom Rate [a]	Diesel fuel Gal/acre [b]	Material: qty a^{-1}	Price per unit	Total materials	Total
Establishment costs per acre:						
Disk	10.00	0.85				10.00
Seedbed conditioning	12.00	0.90				12.00
Sow seed	15.00	0.70	Seed:6 lbs	7.50	45.00	60.00
Spray chemicals	6.00	0.10	Paramount: 8oz	4.00	32.00	38.00
			Atrazine:1 qt	6.00	6.00	6.00
Land rent [f]	55.00					55.00
Total	98.00	2.55			83.00	181.00
Reseeding allowance [d]	24.50	0.64			20.75	45.25
Total establishment	122.50	3.19			103.75	226.25
Annualized establishment cost [e]	18.50	0.48			15.56	33.94
Annual production costs per acre:						
N fertilizer, applied		0.15	70 lbs N a^{-1}	0.43	30.10	30.10
Swath/condition	12.00	0.55				12.00
Baling, large round w/netwrap [g]	53.31	1.8				53.31
Moving bales to edge of farm [g]	8.88	0.9				8.88
Land rent [f]	55.00					\$55.00
Total production year costs	129.19	3.37			30.10	159.29
Total annual & establ. costs	\$147.69	3.84			\$45.66	\$193.23
Per ton DM, at 3 t DM ac-1	\$49.23	1.28			\$15.22	\$64.41

[a] From Jose, 2010

[b] From Hanna, 2001

[c] From Klein, 2010

[d] 25% of initial establishment cost

[e] Amortized over 10 years at 8% discount rate, factor=.14

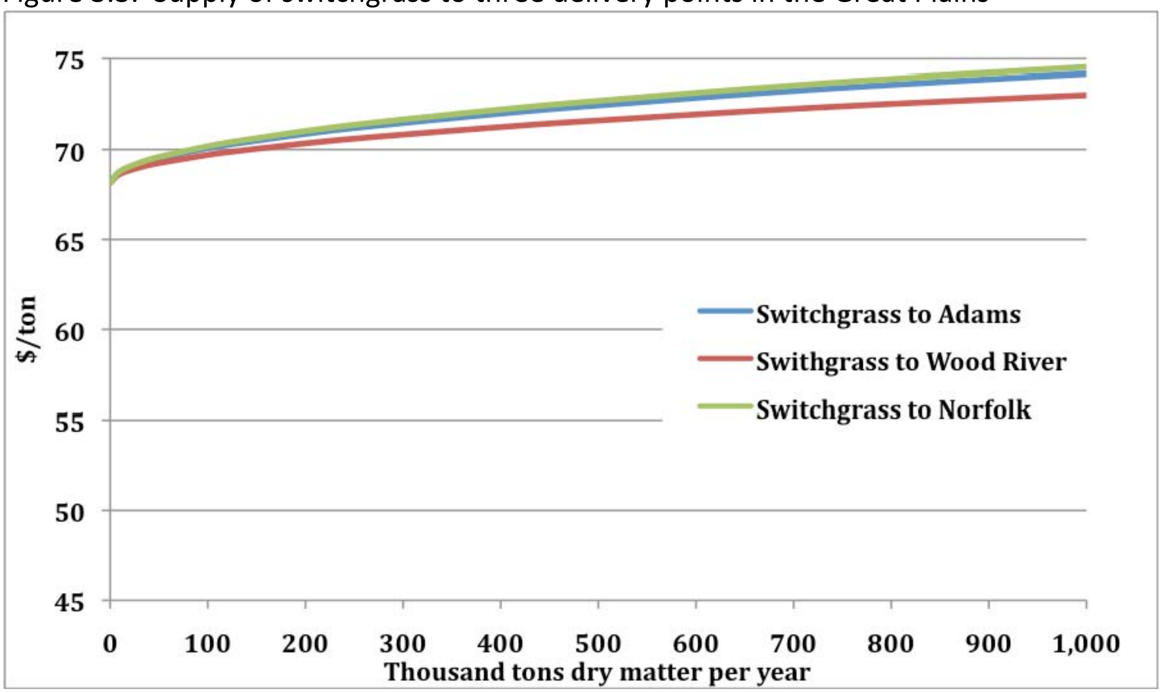
[f] Average cash rent for hay land in 2010 (Johnson, et al, 2010)

[g] At 2.19 bales/a

During production years, fertilization is the only expense other than harvesting costs, and the two together total \$104.29 a^{-1}. Adding land rent of \$55/a (Johnson, et al., 2010) the total of farm-level costs is \$193.23 a^{-1}, or \$64.41 t^{-1} given a yield of 3.0 t a^{-1} during production years. This is our estimate of the $a_k^{switchgrass}$ parameter for all three regions. Combined with the \$3.74 t^{-1} loading/unloading cost, this puts the intercepts for the switchgrass supply curves at \$68.15 t^{-1}. This is well above the prices needed to supply a full one million tons of stover biomass to any of the three delivery points (Figure 2), so it appears from this analysis that switchgrass is not a competitive source of biomass in Nebraska.

Using our estimated parameters and equation (2), supplies of biomass from switchgrass to the three delivery points are depicted in Figure 3.3. Due to the higher potential density of production, the supply curves for switchgrass rise much less steeply than those for corn stover. The average supply radius to supply one million tons is 29 miles, with a transportation cost averaging about \$7 t^{-1} across the three areas.

Figure 3.3. Supply of switchgrass to three delivery points in the Great Plains



The total supply curves for biomass of both types could be calculated as the horizontal summation of supplies for stover and switchgrass, but because switchgrass would not be competitive for deliveries of less than two million tons per year, we do not construct those graphs for this study.

3.4 Discussion

Supplies of biomass might be used in at least three different ways at the delivery points in this study: as fuel for CHP (combined heat and power) in corn ethanol plants; for co-firing with coal in electricity generating plants, or as the feedstock for cellulosic ethanol plants. Helius Energy's biomass power plant project in England, for example, proposes to use 850,000 tons of biomass per year for a 100 MWe power plant (http://www.heliusenergy.com/).

USDA's roadmap for meeting biofuel goals (USDA, 2010) calls for the construction of 226 biorefineries in this (Central East) region, with an average capacity of 40 million gallons per year. A cellulosic ethanol plant of this size would require about 500,000 t of stover or switchgrass per year, at 80 gallons of ethanol per ton. This amount of stover could be delivered to the three points at quite similar prices: about \$58 t^{-1} at Adams, \$53 t^{-1} at Wood River, and \$55 t^{-1} at Norfolk, whereas prices nearly 30% higher would be necessary to provide the required amount of switchgrass (Table 3.6).

Table 3.6. Supply price and radius for supplying alternative biomass facilities

Supply for:	Source:	Result:	Adams	Wood River	Norfolk
40 mgy cellulosic ethanol plant		tons required:	500,000	500,000	500,000
	stover	radius in miles	37.2	23.1	27.3
		price per ton	\$58.19	\$52.81	\$54.70
	switchgrass	radius in miles	17.6	14.2	18.6
		price per ton	\$72.45	\$71.61	\$72.70
CHP for existing corn ethanol plant		tons required:	92,750	204,050	74,200
	stover	radius in miles	16.6	14.6	10.6
		price per ton	\$53.16	\$50.74	\$50.62
	switchgrass	radius in miles	7.9	9.0	8.3
		price per ton	\$70.07	\$70.34	\$70.19

The current corn ethanol plants at these towns have capacities of 50 mgy, 110 mgy and 40 mgy, respectively. At 3.71 lbs of biomass required for heat and power for each gallon of corn ethanol produced, the annual amounts of biomass needed for CHP at these plants are 92,750, 204,050, and 74,200 tons. These quantities would require stover prices of about \$53 t^{-1} at Adams, and \$51 t^{-1} at Wood River and Norfolk. Prices necessary to obtain switchgrass in those quantities would again need to be about 30% higher.

Our cost estimate of a delivered price of about \$53-\$60 per dry ton of corn stover (about \$44 t^{-1} at the farm-gate) is intermediate relative to other recent estimates, as shown in Table 3.7. The transportation components of our supply cost

Table 3.7. Recent cost estimates for delivered corn stover and switchgrass

Author	Publication Year	Cost per dry ton	Location	Comments
CORN STOVER				
This study	2010	$50-60	Nebraska	
Lazarus	2008b	$50	Minnesota	
Brechbill and Tyner	2008	$37-84	Indiana	5-% harvest rate; $4-7 t^{-1} baling cost
Petrolia	2008	$52	Minnesota	Monte Carlo average
Sokhansanj	2006	$38	-	
Gallagher, et al.	2003	$15	Iowa	1997 cost data, 80% harvest rate
Perlack & Turhollow	2003	$43-52	-	
SWITCHGRASS				
This study	2010	$70	Nebraska	
Haque & Epplin	2010	$50-55	Oklahoma	
Sokhansanj, et al.	2009	$28-38	-	4.6-6.9 t ac^{-1}
Wang	2009	$64-139	Tennessee	
Bansund, et al	2008	$35-40	N. Dakota	farm gate cost, no land charge
Brechbill & Tyner	2008	$42-45	Indiana	
Khanna, et al.	2008	$98	Illinois	
Lazarus	2008	$92	Minnesota	
Perrin, et al.	2008	$47-81	Northern Great Plains	Farm records; farm gate cost
Mapemba, et al.	2007	$26-57	Oklahoma	transported: 46-147 miles
Popp & Hogan	2007	$53	Mississippi delta	
Walsh, et al.	2003	$21-40	North Plains	Farmgate price

estimates are somewhat higher than others because we estimate the price necessary to induce production at the perimeter of the supply area, whereas most other studies report the average transportation cost. Gallagher, et al., (2003), provided an early estimate of delivered cost at only about $15 t^{-1}, but that estimate was based on 1997 cost data and on harvest of about 80% of stover, neither of which is realistic for 2009. At about the same time, Perlack and Turhollow estimated the delivered cost at $43-53 t^{-1}, and later estimates have also been in the vicinity of $40-50 t^{-1}.

Our cost estimate for delivered switchgrass, about $70 t^{-1} ($65 t^{-1} at the farm gate) is somewhat higher than many other recent estimates, which have varied greatly from about $25 to over $100 t^{-1}. Our estimate is quite consistent with the average cost from ten on-farm trials during 2000-2005, $60 t^{-1} at the farm gate as reported by Perrin, et al. It is also consistent with prices for generic grass hay reported in Nebraska during 2008-2010, which have been in the range of $70-90 t^{-1} (*Cornhusker Economics*, various issues). The highest costs reported in other studies in Table 3.7 were budget estimates for high-rent corn land in the central cornbelt, while the lowest cost estimates were for drier areas of the Great Plains.

A number of considerations would lead to shifts in the supply curves we have estimated, among them being changes in diesel prices, government programs, or different yields. Diesel requirements (other than for trucking) total about 1.4 gal t^{-1} for both stover and switchgrass. At $3 gal^{-1}, this fuel cost is $4.20 t^{-1}. Thus a doubling of diesel price would shift the supply curve intercepts up by $4.20 t^{-1}, equivalent to about 6% of the switchgrass intercept and 8% of that for stover. Similarly, at $3 gal^{-1}, diesel comprises about 10% of the transportation cost component, so the slopes of the supply curves would increase about 10% if diesel price were to double to $6/gal.

USDA's Biomass Crop Assistance Program (BCAP) promises to match buyers' payments to farmers, which implies that the price at which producers would be willing to supply could be as little as half the prices shown on these supply schedules. However, the legislation limits payments to two years, which would limit this impact, especially for switchgrass which requires several years of harvests to bring amortized establishment costs down to competitive levels. Thus, BCAP might lower the supply curves for stover somewhat, but would have little effect on our switchgrass supply estimates.

Higher per-acre yields for either of these biomass crops would lower these supply curves, but not proportionately because a relatively small fraction of supply costs are fixed with respect to yield. In the case of switchgrass, for example, only the establishment cost and the cost for swathing are fixed with respect to yield, and together they comprise only about 25% of the cost of putting a ton of switchgrass on a truck for transportation to a delivery point. Thus a given percentage increase in yield per acre would reduce the intercepts of the supply curves by only 25% of that percentage. For example, increasing switchgrass yields by 100%, from 3 tons per acre to 6 tons per acre, would reduce the intercept of the supply curve by only 25%, from $68 t^{-1} to $50 t^{-1}. A yield increase of about this amount would be necessary to make switchgrass competitive with corn stover as a biomass source in this region.

In addition to these considerations, it is possible that producers would undervalue the $17 t^{-1} worth of crop nutrients removed with each ton of corn stover. In this case the stover supply curves could shift downward by as much as $17 t^{-1},with an intercept of about $35 t^{-1} rather than $50 t^{-1}, and the price required to supply one million tons would fall to around \$45 t^{-1}. However, failure to replace nutrients would surely reduce future yields and hence, increase future cost per ton delivered.

3.5 Conclusions

This study has shown that up to one million tons of corn stover biomass annually could be delivered to points in Nebraska at prices of about \$55-60 per ton of dry matter. Switchgrass, on the other hand, would require prices of nearly \$70 per ton to be supplied in these quantities. Switchgrass thus does not appear to be competitive with stover as a biomass source at current technology and prices. Differences across the three delivery points in acreage densities and yields affect the stover supply price by as much as 10%, but have little effect on switchgrass supply prices. The amount of biomass required at the delivery point does have an impact on prices required, with small amounts of stover available at about \$50 t^{-1}, but to supply a million tons per year a price of about \$60 would be required.

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4. Changes in Soil Organic Carbon and Greenhouse Gas Emissions from Crop Residue Removal for Corn-Ethanol Biorefineries with Combined Heat and Power (Adam J. Liska[1,2], Xiao Xue Fang[1], and Maribeth Milner[2])

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4.1. Soil organic carbon and nitrous oxide emissions in production regions for CHP

Maintaining SOC has been shown to be essential for sustaining crop productivity (Wilhelm 2004). Previous research has shown that crop residue removal tends to reduce SOC and this limits residue availability if maintaining soil quality and productivity is a goal (Wilhelm et al. 2007, Anderson-Teixeira et al. 2008). Such research is in contradiction to recent studies that only focused on limiting impacts from soil erosion and indicated crop residue could be exploited sustainably (Graham et al. 2007). In addition, inclusion of this SOC loss as a resulting GHG emission (as CO_2) in LCA has been shown to be a significant emission in the life cycle (Wortmann et al. 2010). The DK model was used below to analyze changes in SOC from residue removal for CHP in three regions in eastern Nebraska (**Fig. 4.1**), centered on the towns of Adams, Norfolk, and Wood River. For the LCA, we compared three cropping systems to estimate changes in SOC from biomass production for CHP due to crop residue removal (**Tables 4.1-4.3**).

Figure 4.1. Soil organic carbon levels in eastern Nebraska in the top 20 cm (STATSGO 2008). Saunders county was used to calibrate the DK model (Appendix I.).

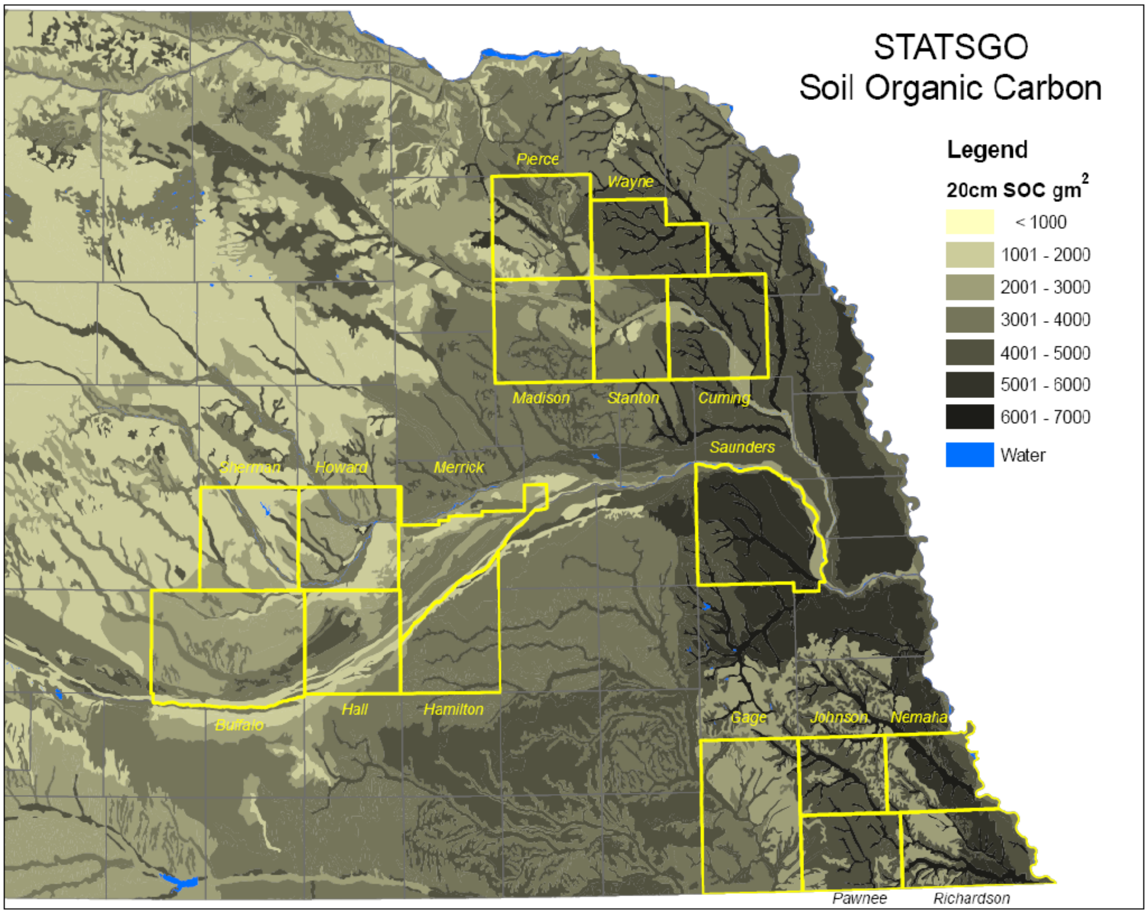


Table 4.1. Net changes in soil organic carbon (SOC) using the DK model (Yang 2000) due to crop residue removal.

Adams biorefinery								
Reference systems				**Biomass removal systems**				**Net Δ**
#	**Crop**	**Harvest**	**Δ SOC Mg C ha^{-1} yr^{-1}**	**#**	**Crop**	**Harvest**	**Δ SOC Mg C ha^{-1} yr^{-1}**	**Δ SOC Mg C ha^{-1} yr^{-1}**
R1	Continuous corn	Grain removal	-0.909	R3	Continuous corn	Grain + 25% residue removal	-1.14	-0.227
R2	Corn-soybean rotation	Grain removal	-1.07	R3	Continuous corn	Grain + 25% residue removal	-1.22	-0.147
Norfolk biorefinery								
Reference systems				**Biomass removal systems**				**Net Δ**
#	**Crop**	**Harvest**	**Δ SOC Mg C ha^{-1} yr^{-1}**	**#**	**Crop**	**Harvest**	**Δ SOC Mg C ha^{-1} yr^{-1}**	**Δ SOC Mg C ha^{-1} yr^{-1}**
R1	Continuous corn	Grain removal	-0.377	R3	Continuous corn	Grain + 25% residue removal	-0.642	-0.265
R2	Corn-soybean rotation	Grain removal	-0.573	R3	Continuous corn	Grain + 25% residue removal	-0.740	-0.167
Wood River biorefinery								
Reference systems				**Biomass removal systems**				**Net Δ**
#	**Crop**	**Harvest**	**Δ SOC Mg C ha^{-1} yr^{-1}**	**#**	**Crop**	**Harvest**	**Δ SOC Mg C ha^{-1} yr^{-1}**	**Δ SOC Mg C ha^{-1} yr^{-1}**
R1	Continuous corn	Grain removal	-0.152	R3	Continuous corn	Grain + 25% residue removal	-0.444	-0.292
R2	Corn-soybean rotation	Grain removal	-0.359	R3	Continuous corn	Grain + 25% residue removal	-0.548	-0.188

Corn residue removal carbon dynamics

Microbiological oxidation of SOC is constantly diminishing the existing carbon stock to carbon dioxide (CO_2) gas. Over time, the SOC pool is equal to the initial level of carbon (C), minus C loss via oxidation, plus C additions from new substrates (Johnson et al. 2010). Plant residues, including both aboveground biomass and roots, are the major

C inputs to agricultural fields (Stevenson 1986). In an unmanaged landscape, most plant reside returns to the soil. In cultivated fields, however, generally at least half of the total aboveground biomass is removed from the fields via grain harvest. Along with intensive tillage, this largely explains the observed decline of SOC level once a field is cultivated after being under natural vegetation. Once decomposition starts, temperature is the most important regulator for the speed of the process (Yang and Janssen 2000). Another characteristic of C oxidation is that a substrate's decomposability decreases exponentially over time, leading quickly to a slowing down of the rate of the process, reaching a steady-state. In the US Corn Belt, about 30% of plant materials will remain in soil after one year, and about 18% and 12% will remain after 5 years and 10 years, respectively (personal communication, Haishun Yang; Jenkinson 1977). Alternatively, after a cultivated soil is returned to a perennial grass, SOC can accumulate and saturate at a relatively constant level (Stevenson 1986, p.58; Liebig 2005).

Determining carbon inputs for DK modeling of soil carbon dynamics

In order to estimate the carbon input to soil required for running the DK simulation, a set of parameters and assumptions for corn and soybean were obtained from the literature (**Table 4.2**). Based on the grain yield and harvest index for corn and soybean for the three regions, the aboveground biomass residue (dry matter) for each crop type was calculated and converted to its equivalent biomass carbon using the appropriate ratio of carbon content of aboveground biomass. The root biomass carbon was estimated in a similar way. The total carbon input for all counties in the three regions from year 2006 to 2008 was then calculated as the sum of aboveground biomass carbon and the root biomass carbon (**Tables 4.4-4.7**). For the biomass removal systems, the carbon input from aboveground biomass residue was reduced by 50%. For all counties surrounding the three CHP biorefineries, the grain and biomass residue yields (dry matter), and total C inputs for the reference system R2 with corn-soybean rotation were also reported (**Tables 4.8-4.10**). This system was included because it more closely approximates currently cropping rotations, in comparison with continuous corn (R1 and R3), which is a more limited fraction of current corn production in Nebraska.

Table 4.2. Parameters and assumptions for calculating carbon inputs from corn and soybean in the top 30 centimeters.

Parameter values	Parameters for estimating carbon input to soil
Corn	
56	Pounds per bushel
15.5%	Moisture fraction of reported grain yield
0.53	Harvest index (grain, dm /total aboveground biomass, dm) (Johnson *et al*. 2006)
40%	Carbon content of aboveground biomass (Johnson *et al*. 2006)
29%	Root carbon as ratio of aboveground biomass carbon (Amos Walters 2006)
66%	Root carbon in top 30 cm (Jones and Kiniry 1986, Yang *et al*. 2006)
Soybean	
60	Pounds per bushel
13%	Moisture fraction of reported grain yield
0.46	Harvest index (grain, dm /total aboveground biomass, dm) (Johnson *et al*. 2006)
40%	Carbon content of shoot and root (Johnson *et al*. 2006)
14%	Root biomass as ratio of total aboveground biomass (Tri *et al*. 2010)
66%	Root carbon in top 30 cm (Jones and Kiniry 1986, Yang *et al*. 2006)

Soil carbon response to carbon inputs in the DK model

To test the model's response to differences in carbon inputs with and without residue removal, the SOC loss for CSP site 1 was estimated using averaged carbon inputs over four years (**Table 4.3).** Greater SOC losses occurred as the percentage of residue removal increased according to the DK model **(Fig. 4.2**). An SOC input of 6.3 Mg C ha^{-1} yr^{-1} would be required to prevent any SOC loss at CSP site 1. With no residue removal, a SOC loss of 0.53 Mg C ha^{-1} yr^{-1} was observed using the generalized carbon input. DK simulation with actual carbon input measured directly from the field yielded a SOC loss of 0.36 Mg C ha^{-1} yr^{-1} (**Table A2, Appendix I**).

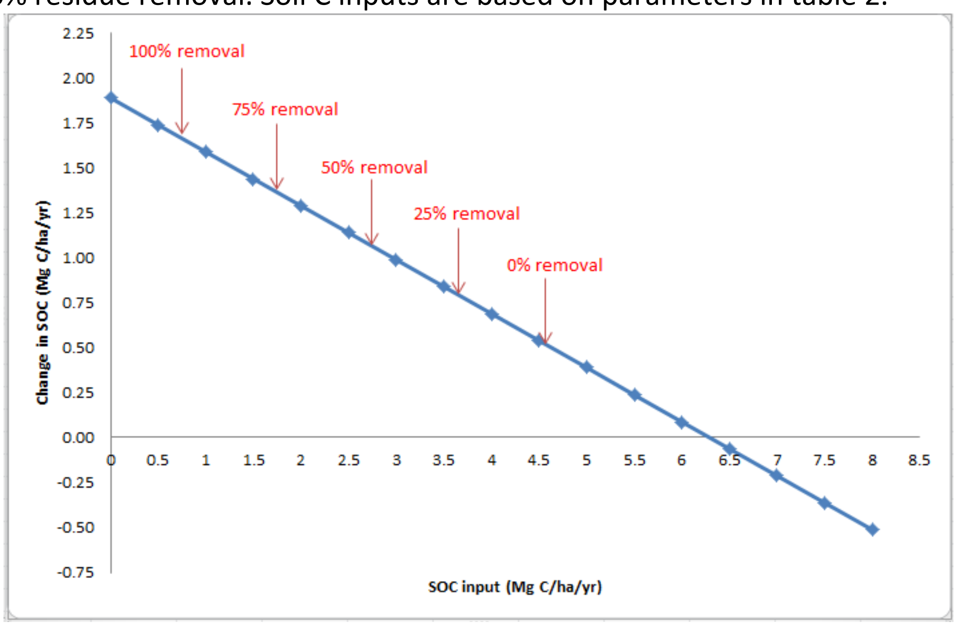
Direct comparison of these results suggested an overestimation of SOC loss when estimating carbon input to soil based on parameters and assumptions from literature. This discrepancy is the direct consequence of uncertainties present in calculation of the soil decay process. There are limitations associated with the model itself for being insensitive to moisture level and tillage, thus contributing errors to the DK simulated outputs for SOC losses. In estimating the generalized carbon input for CSP site 1 (from table 2), multiple steps of calculations were required for reaching a final carbon input value used in the model, resulting in propagation of errors in the process.

The degree of error can be magnified especially when there are uncertainties present in the literature values used for this analysis.

Table 4.3. Estimated SOC inputs and DK simulated outputs for CSP site 1 with 25, 50, 75, and 100% residue removal from 2001 to 2005. SOC inputs below are averages. Soil C inputs are based on parameters in Table 2.

Year	**% Residue Removal**	**SOC Inputs (Mg C/ha)**	**SOC, 2001 (Mg C/ha)**	**SOC, 2005 (Mg C/ha)**	**ΔSOC, 2001-05 (Mg C/ha)**	**ΔSOC, 2001-05 (Mg C/ha/yr)**
2001-05	0	4.54	69.5	67.39	-2.11	**-0.53**
2001-05	25	3.59	69.5	66.25	-3.25	-0.81
2001-05	50	2.63	69.5	65.10	-4.40	-1.10
2001-05	75	1.68	69.5	63.96	-5.54	-1.39
2001-05	100	0.73	69.5	62.82	-6.68	-1.67

Figure 4.2. SOC inputs and corresponding losses of SOC for CSP site 1 with 0, 25, 50, 75, and 100% residue removal. Soil C inputs are based on parameters in table 2.



Carbon inputs for county-level DK modeling—corn

In this section, we estimated carbon inputs to soil from continuous corn based on county level yield data (**Tables 4.4-4.6**), with and without residue removal. Below is a map showing regional corn and soybean distribution relative to the biorefineries in question (**Fig. 4.3**).

Figure 4.3. High-resolution map showing corn and soybean cropland (NASS 2008).

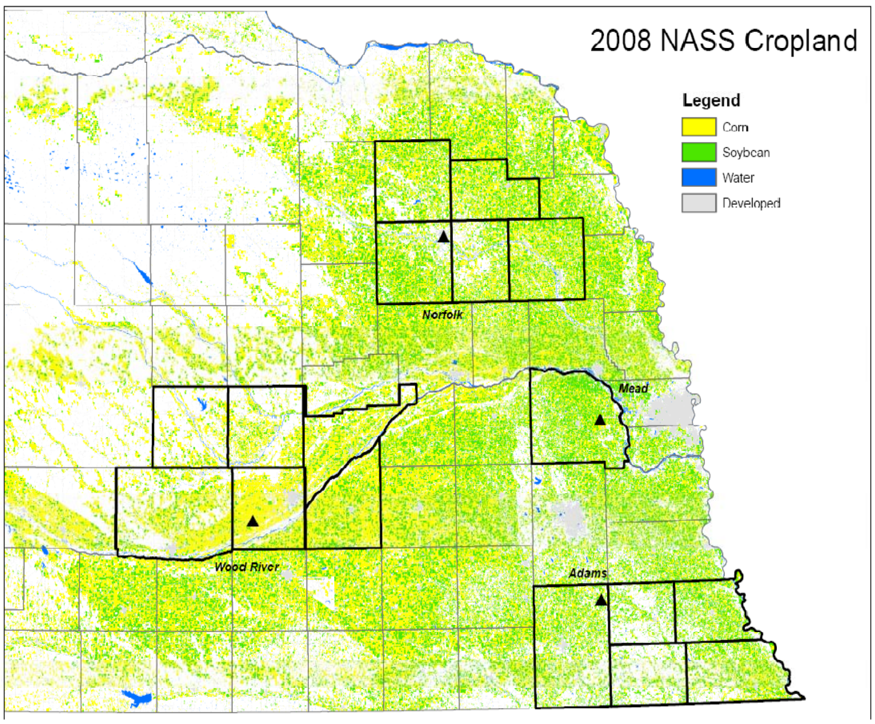


Table 4.4. Grain and biomass residue yields (dry matter), and total C inputs without residue removal, and with 50% residue removal in surrounding counties at the **Adams** plant from 2006 to 2008. Soil C inputs are based on parameters in table 2.***R1**R3.**

County	year	yield (bu/acres)	yield (Mg/ha)	grain dm (Mg/ha)	biomass residue dm (Mg/ha)	biomass residue (Mg C/ha)	root biomass (Mg C/ha)	total C input (*) (Mg C/ha)	average C input (*) (Mg C/ha)	biomass removed (Mg C/ha)	total C input (**) (Mg C/ha)	average C input (**) (Mg C/ha)
Gage	2006	131	8.23	6.95	6.17	2.47	0.47	2.94	2.90	-1.23	1.71	1.68
Gage	2007	117	7.33	6.20	5.49	2.20	0.42	2.62		-1.10	1.52	
Gage	2008	141	8.83	7.46	6.62	2.65	0.51	3.15		-1.32	1.83	
Johnson	2006	103	6.50	5.49	4.87	1.95	0.37	2.32	2.72	-0.97	1.35	1.58
Johnson	2007	131	8.25	6.97	6.18	2.47	0.47	2.94		-1.24	1.71	
Johnson	2008	130	8.14	6.88	6.10	2.44	0.47	2.91		-1.22	1.69	
Nemaha	2006	108	6.80	5.74	5.09	2.04	0.39	2.43	2.94	-1.02	1.41	1.70
Nemaha	2007	142	8.94	7.56	6.70	2.68	0.51	3.19		-1.34	1.85	
Nemaha	2008	142	8.93	7.55	6.69	2.68	0.51	3.19		-1.34	1.85	
Pawnee	2006	105	6.61	5.58	4.95	1.98	0.38	2.36	2.68	-0.99	1.37	1.55
Pawnee	2007	121	7.60	6.42	5.70	2.28	0.44	2.72		-1.14	1.58	
Pawnee	2008	132	8.27	6.99	6.20	2.48	0.47	2.95		-1.24	1.71	
Richardson	2006	135	8.47	7.16	6.35	2.54	0.49	3.03	3.04	-1.27	1.76	1.77
Richardson	2007	132	8.27	6.99	6.20	2.48	0.47	2.95		-1.24	1.71	
Richardson	2008	141	8.82	7.45	6.61	2.64	0.51	3.15		-1.32	1.83	

Table 4.5. Grain and biomass residue yields (dry matter), and total C input without residue removal, and with 50% residue removal in surrounding counties at the **Norfolk** plant from 2006 to 2008. Soil C inputs are based on parameters in table 2. ***R1**R3.**

County	year	yield (bu/acres)	yield (Mg/ha)	grain dm (Mg/ha)	biomass residue dm (Mg/ha)	biomass residue (Mg C/ha)	root biomass (Mg C/ha)	total C input (*) (Mg C/ha)	average C input (*) (Mg C/ha)	biomass removed (Mg C/ha)	total C input (**) (Mg C/ha)	average C input (**) (Mg C/ha)
Cuming	2006	145	9.10	7.69	6.82	2.73	0.52	3.25	3.49	-1.36	1.89	2.03
Cuming	2007	162	10.15	8.58	7.61	3.04	0.58	3.63		-1.52	2.10	
Cuming	2008	160	10.07	8.51	7.54	3.02	0.58	3.60		-1.51	2.09	
Madison	2006	141	8.85	7.48	6.63	2.65	0.51	3.16	3.31	-1.33	1.83	1.92
Madison	2007	153	9.58	8.09	7.18	2.87	0.55	3.42		-1.44	1.98	
Madison	2008	150	9.41	7.95	7.05	2.82	0.54	3.36		-1.41	1.95	
Pierce	2006	142	8.90	7.52	6.67	2.67	0.51	3.18	3.51	-1.33	1.84	2.04
Pierce	2007	156	9.82	8.30	7.36	2.94	0.56	3.51		-1.47	2.03	
Pierce	2008	171	10.76	9.09	8.06	3.23	0.62	3.84		-1.61	2.23	
Stanton	2006	123	7.69	6.50	5.76	2.31	0.44	2.75	3.17	-1.15	1.59	1.84
Stanton	2007	160	10.02	8.47	7.51	3.00	0.57	3.58		-1.50	2.08	
Stanton	2008	143	8.96	7.57	6.71	2.68	0.51	3.20		-1.34	1.86	
Wayne	2006	110	6.89	5.82	5.16	2.07	0.40	2.46	3.23	-1.03	1.43	1.87
Wayne	2007	155	9.73	8.22	7.29	2.92	0.56	3.47		-1.46	2.02	
Wayne	2008	167	10.50	8.88	7.87	3.15	0.60	3.75		-1.57	2.18	

Table 4.6. Grain and biomass residue yields (dry matter), and total C input without residue removal, and with 50% residue removal in surrounding counties at the **Wood River** plant from 2006 to 2008. Soil C inputs are based on parameters in table 2. ***R1**R3.**

Wood River County	year	yield (bu/acres)	yield (Mg/ha)	grain dm (Mg/ha)	biomass residue dm (Mg/ha)	biomass residue (Mg C/ha)	root biomass (Mg C/ha)	total C input (*) (Mg C/ha)	average C input (*) (Mg C/ha)	biomass removed (Mg C/ha)	total C input (**) (Mg C/ha)	average C input (**) (Mg C/ha)
Buffalo	2006	176	11.03	9.32	8.27	3.31	0.63	3.94	3.92	-1.65	2.29	2.28
Buffalo	2007	176	11.07	9.36	8.30	3.32	0.64	3.95		-1.66	2.29	
Buffalo	2008	173	10.85	9.17	8.13	3.25	0.62	3.88		-1.63	2.25	
Hall	2006	184	11.57	9.78	8.67	3.47	0.66	4.13	4.03	-1.73	2.40	2.34
Hall	2007	184	11.55	9.76	8.66	3.46	0.66	4.12		-1.73	2.39	
Hall	2008	171	10.74	9.08	8.05	3.22	0.62	3.84		-1.61	2.23	
Howard	2006	156	9.80	8.28	7.35	2.94	0.56	3.50	3.56	-1.47	2.03	2.07
Howard	2007	157	9.83	8.31	7.37	2.95	0.56	3.51		-1.47	2.04	
Howard	2008	164	10.28	8.69	7.70	3.08	0.59	3.67		-1.54	2.13	
Sherman	2006	153	9.62	8.13	7.21	2.88	0.55	3.44	3.63	-1.44	1.99	2.11
Sherman	2007	163	10.24	8.65	7.67	3.07	0.59	3.66		-1.53	2.12	
Sherman	2008	170	10.65	9.00	7.98	3.19	0.61	3.80		-1.60	2.21	
Hamilton	2006	182	11.43	9.66	8.57	3.43	0.66	4.08	4.13	-1.71	2.37	2.40
Hamilton	2007	179	11.24	9.49	8.42	3.37	0.64	4.01		-1.68	2.33	
Hamilton	2008	192	12.04	10.17	9.02	3.61	0.69	4.30		-1.80	2.50	
Merrick	2006	171	10.74	9.07	8.05	3.22	0.62	3.84	3.57	-1.61	2.23	2.07
Merrick	2007	153	9.63	8.14	7.21	2.89	0.55	3.44		-1.44	2.00	
Merrick	2008	154	9.64	8.15	7.22	2.89	0.55	3.44		-1.44	2.00	

Carbon inputs for county-level DK modeling—soybean

Soil carbon inputs from soybean are roughly one third of carbon inputs from corn, because of lower crop yields. As is clear from the images below (**Fig. 4.4 and 4.5**), after harvest, substantially less residue is left after a soybean crop compared to a corn crop. We estimated soil carbon inputs from soybean (**Table 4.2 and 4.7**) for all counties in 2007. We included this data in a corn-soybean rotation as a R2 reference system to residue removal (**Tables 4.8-4.10**).

Table 4.7. Soybean yields in 2007 for **<u>all counties</u>**. Soil C inputs are based on parameters in table 2 for baseline system **R2** (described in Table 1). Soil C inputs are based on parameters in table 2.

County	**yield (bu/acres)**	**yield (Mg/ha)**	**grain dm (Mg,dm/ha)**	**biomass residue (Mg,dm/ha)**	**root biomass (Mg,dm/ha)**	**biomass residue (Mg C/ha)**	**root biomass (Mg C/ha)**	**total C input (Mg C/ha)**
Gage	40.6	2.73	2.38	2.79	0.72	1.12	0.19	1.31
Johnson	44.5	2.99	2.60	3.06	0.79	1.22	0.21	1.43
Nemaha	51.3	3.45	3.00	3.52	0.91	1.41	0.24	1.65
Pawnee	45.1	3.03	2.64	3.10	0.80	1.24	0.21	1.45
Richardson	51.0	3.43	2.98	3.50	0.91	1.40	0.24	1.64
Cuming	54.3	3.65	3.18	3.73	0.97	1.49	0.26	1.75
Madison	50.2	3.38	2.94	3.45	0.89	1.38	0.24	1.62
Pierce	47.7	3.21	2.79	3.28	0.85	1.31	0.22	1.53
Stanton	50.0	3.36	2.93	3.43	0.89	1.37	0.24	1.61
Wayne	51.3	3.45	3.00	3.52	0.91	1.41	0.24	1.65
Buffalo	55.8	3.75	3.26	3.83	0.99	1.53	0.26	1.80
Hall	58.8	3.95	3.44	4.04	1.05	1.62	0.28	1.89
Howard	51.4	3.46	3.01	3.53	0.92	1.41	0.24	1.65
Sherman	53.4	3.59	3.12	3.67	0.95	1.47	0.25	1.72
Hamilton	58.3	3.92	3.41	4.00	1.04	1.60	0.27	1.88
Merrick	53.3	3.58	3.12	3.66	0.95	1.46	0.25	1.71

Figure 4.4. Corn residue as a soil input after harvest on February 21, 2009 in Jefferson county in southeastern Nebraska. Photograph by Adam J. Liska.

Figure 4.5. Soybean residue as a soil input after harvest on February 21, 2009 in Jefferson county in southeastern Nebraska, having roughly one third the biomass of corn residue. Photograph by Adam J. Liska.

Table 4.8. Grain and biomass residue yields (dry matter), and total C input without residue removal in surrounding counties at the **Adams** plant from 2006 to 2008. Soil C inputs are based on parameters in table 2.*****R2.**

Adams County	**year**	**Crop**	**yield** (bu/acres)	**yield** (Mg/ha)	**grain dm** (Mg/ha)	**biomass residue dm (Mg/ha)**	**biomass residue (Mg C/ha)**	**root biomass (Mg C/ha)**	**total C input (***) (Mg C/ha)**	**average C input(***) (Mg C/ha)**
Gage	2006	corn	131	8.23	6.95	6.17	2.47	0.47	2.94	2.47
Gage	2007	soybean	40.60	2.73	2.38	2.79	1.12	0.19	1.31	
Gage	2008	corn	141	8.83	7.46	6.62	2.65	0.51	3.15	
Johnson	2006	corn	103	6.50	5.49	4.87	1.95	0.37	2.32	2.22
Johnson	2007	soybean	45	2.99	2.60	3.06	1.22	0.21	1.43	
Johnson	2008	corn	130	8.14	6.88	6.10	2.44	0.47	2.91	
Nemaha	2006	corn	108	6.80	5.74	5.09	2.04	0.39	2.43	2.42
Nemaha	2007	soybean	51	3.45	3.00	3.52	1.41	0.24	1.65	
Nemaha	2008	corn	142	8.93	7.55	6.69	2.68	0.51	3.19	
Pawnee	2006	corn	105	6.61	5.58	4.95	1.98	0.38	2.36	2.25
Pawnee	2007	soybean	45	3.03	2.64	3.10	1.24	0.21	1.45	
Pawnee	2008	corn	132	8.27	6.99	6.20	2.48	0.47	2.95	
Richardson	2006	corn	135	8.47	7.16	6.35	2.54	0.49	3.03	2.61
Richardson	2007	soybean	51	3.43	2.98	3.50	1.40	0.24	1.64	
Richardson	2008	corn	141	8.82	7.45	6.61	2.64	0.51	3.15	

Table 4.9. Grain and biomass residue yields (dry matter), and total C input without residue removal in surrounding counties at the **Norfolk** plant from 2006 to 2008. Soil C inputs are based on parameters in table 2. *****R2.**

Norfolk County	**year**	**Crop**	**yield (bu/acres)**	**yield (Mg/ha)**	**grain dm (Mg/ha)**	**biomass residue dm (Mg/ha)**	**biomass residue (Mg C/ha)**	**root biomass (Mg C/ha)**	**total C input (***) (Mg C/ha)**	**average C input (***) (Mg C/ha)**
Cuming	2006	corn	145	9.10	7.69	6.82	2.73	0.52	3.25	2.86
Cuming	2007	soybean	54	3.65	3.18	3.73	1.49	0.26	1.75	
Cuming	2008	corn	160	10.07	8.51	7.54	3.02	0.58	3.60	
Madison	2006	corn	141	8.85	7.48	6.63	2.65	0.51	3.16	2.71
Madison	2007	soybean	50	3.38	2.94	3.45	1.38	0.24	1.62	
Madison	2008	corn	150	9.41	7.95	7.05	2.82	0.54	3.36	
Pierce	2006	corn	142	8.90	7.52	6.67	2.67	0.51	3.18	2.85
Pierce	2007	soybean	47.70	3.21	2.79	3.28	1.31	0.22	1.53	
Pierce	2008	corn	171	10.76	9.09	8.06	3.23	0.62	3.84	
Stanton	2006	corn	123	7.69	6.50	5.76	2.31	0.44	2.75	2.52
Stanton	2007	soybean	50	3.36	2.93	3.43	1.37	0.24	1.61	
Stanton	2008	corn	143	8.96	7.57	6.71	2.68	0.51	3.20	
Wayne	2006	corn	110	6.89	5.82	5.16	2.07	0.40	2.46	2.62
Wayne	2007	soybean	51	3.45	3.00	3.52	1.41	0.24	1.65	
Wayne	2008	corn	167	10.50	8.88	7.87	3.15	0.60	3.75	

Table 4.10. Grain and biomass residue yields (dry matter), and total C input without residue removal in surrounding counties at the **<u>Wood River</u>** plant from 2006 to 2008. Soil C inputs are based on parameters in table 2. ***R2.

Wood River County	**year**	**Crop**	**yield (bu/acres)**	**yield (Mg/ha)**	**grain dm (Mg/ha)**	**biomass residue dm (Mg/ha)**	**biomass residue (Mg C/ha)**	**root biomass (Mg C/ha)**	**total C input (***) (Mg C/ha)**	**average C input (***) (Mg C/ha)**
Buffalo	2006	corn	176	11.03	9.32	8.27	3.31	0.63	3.94	3.20
Buffalo	2007	soybean	56	3.75	3.26	3.83	1.53	0.26	1.80	
Buffalo	2008	corn	173	10.85	9.17	8.13	3.25	0.62	3.88	
Hall	2006	corn	184	11.57	9.78	8.67	3.47	0.66	4.13	3.29
Hall	2007	soybean	59	3.95	3.44	4.04	1.62	0.28	1.89	
Hall	2008	corn	171	10.74	9.08	8.05	3.22	0.62	3.84	
Howard	2006	corn	156	9.80	8.28	7.35	2.94	0.56	3.50	2.94
Howard	2007	soybean	51	3.46	3.01	3.53	1.41	0.24	1.65	
Howard	2008	corn	164	10.28	8.69	7.70	3.08	0.59	3.67	
Sherman	2006	corn	153	9.62	8.13	7.21	2.88	0.55	3.44	2.99
Sherman	2007	soybean	53	3.59	3.12	3.67	1.47	0.25	1.72	
Sherman	2008	corn	170	10.65	9.00	7.98	3.19	0.61	3.80	
Hamilton	2006	corn	182	11.43	9.66	8.57	3.43	0.66	4.08	3.42
Hamilton	2007	soybean	58	3.92	3.41	4.00	1.60	0.27	1.88	
Hamilton	2008	corn	192	12.04	10.17	9.02	3.61	0.69	4.30	
Merrick	2006	corn	171	10.74	9.07	8.05	3.22	0.62	3.84	3.00
Merrick	2007	soybean	53	3.58	3.12	3.66	1.46	0.25	1.71	
Merrick	2008	corn	154	9.64	8.15	7.22	2.89	0.55	3.44	

SOC Parameters for county-level modeling: Baseline data from SSURGO

Representative values of county level 30 cm agronomic soil organic matter (SOM) were determined from USDA-NRCS Soil Survey Geographic (SSURGO) 1:24,000 data bases and converted to soil organic carbon (SOC) by dividing by 2 (Pribyl 2010). Agronomic soils were delineated as the area planted to corn or soybeans in the 2008 USDA-NASS Cropland Data Layer (56 m resolution). A grid of corn and soybean for each region of interest was created and converted to polygons for which the SSURGO map units were clipped. The areal extent associated with each map unit was calculated, and the soil organic carbon concentration levels (g per kg soil) and soil bulk densities (g per cm^3) were estimated and averaged over multiple horizons for each county.

There are several sources of errors associated with using SSURGO, one of them coming from the soil model itself. It is often difficult to identify the dominant soil forming processes or soil map units in an area with great precision both in aerial photos and in the field. Depending upon landscape position, the soil order in a particular area could be very different from its adjacent land. The boundaries for a soil model are sometimes difficult to define as the rate of transition from one map unit into another varies among different soil types. Sampling errors could also occur when characterizing soil properties for an area depending on the number of representative sites identified for each soil map unit. The uncertainties associated with using SSURGO data could be reflected in the estimations for county-level soil carbon concentrations and bulk densities used in the DK model.

Climate data for county-level DK modeling

DK model requires weather data to estimate soil decomposition rates; only maximum and minimum daily temperature. Model runs showed a significant difference in calculated SOC loss when alternative nearby weather station data was used from other counties, compared to the closest county-level station. This indicates that to estimate changes in SOC for a county, the most accurate weather data will be used from a local weather station resident in the county under analysis. Below is a map showing AWDN weather stations in the High Plains Regional Climate Center in Nebraska used selectively for DK modeling (**Fig. 4.6**). For our analysis, a combination of AWDN and COOP weather stations were used for temperature data (daily max, min) to ensure that the closest weather station was identified for each county (**Table 4.11**). These stations were selected to reduce uncertainties associated with temperature-related parameters in the DK model.

Figure 4.6. Weather stations in the High Plains Regional Climate Center used selectively for temperature data (daily max, min) for DK modeling. (http://www.hprcc.unl.edu/awdn/files/AWDN_NE.pdf)

Table 4.11. Surrounding AWDN and COOP weather stations for counties under study.

County	AWDN weather station	COOP weather station
Nemaha	Indian Cave St. Park a254119	
Gage	Beatrice-a250629	
Johnson	-	Tecumseh-c258465
Pawnee	-	Pawnee city-c256570
Richardson	Indian Cave St. Park a254119	
Stanton	-	Stanton-c258110
Pierce	Brunswick, Antelope co. a251249	
Madison	Elgin, Antelope co. a252599	
Wayne		Wayne-c259045
Cuming	Westpoint-a259209	
Sherman	Ord, Valley co. a256339	
Hamilton	Central City, Merrick co. a251569	
Merrick	Central City-a251569	
Buffalo	Kearny-a254339	
Hall	Grand Island-a253409	
Howard	-	Dannebrog-c252162

County-level DK modeling of soil carbon dynamics—with residue removal

Baling and removal of corn residue is clearly shown to dramatically reduce residue cover and potential soil carbon inputs (**Fig. 4.7**). Using the carbon inputs from Tables 4-7 for corn and soybean, soil characteristics estimated by SSURGO, and weather data obtained from AWDN and COOP stations as weather file inputs for the DK model, we estimated the SOC loss for each biorefinery under both a reference and a biomass removal system (**Tables 4.12 and 4.13**). Specifically, we compared systems with continuous corn to continuous corn plus 25% residue removal (R1 vs. R3); and systems with corn-soybean rotation to continuous corn plus 25% residue removal (R2 vs. R3). While both systems showed a loss in SOC levels due to residue removal, differences in SOC dynamics between the systems is more pronounced for the comparison of continuous corn to continuous corn with removal (R1 vs. R3).

Table 4.12. Summary of SOC losses for the three biorefineries under systems R1 vs. R3. Total C loss rates (first row) correspond to the entire corn area in the surrounding counties under these systems.

Plant	Adams	Norfolk	Wood River	Average
ΔSOC (Mg C yr^{-1})	-37,863	-67,350	-108,686	-71,300
ΔSOC (Mg C ha^{-1} yr^{-1})	-0.227	-0.265	-0.292	-0.261

Table 4.13. Summary of SOC losses for the three biorefineries under systems R2 vs. R3.

Plant	Adams	Norfolk	Wood River	Average
ΔSOC (Mg C yr^{-1})	-24,000	-42,596	-80,000	-48,865
ΔSOC (Mg C $ha^{-1}yr^{-1}$)	-0.147	-0.167	-0.188	-0.167

Figure 4.7. Corn residue removal on February 21, 2009 in Jefferson county in southeastern Nebraska. Photograph by Adam J. Liska.

Detailed analysis of soil carbon dynamics characterized by relative SOC loss for the biorefinery at each of the three regions are presented in **Tables 4.14-4.19** for the two sets of systems under study. Because it is both labor and machinery intensive to remove 25% of residue from the whole field, 50% residue removal was performed on 50% of the area instead (consistent with the economic analysis by Perrin et al.). For systems with continuous corn (R1) and corn-soybean rotation (R2), soil carbon levels generated by DK simulation were converted to SOC losses expressed in Mg C yr^{-1} for 100% of the area. For system with continuous corn plus residue removal (R3), total SOC losses were calculated as the sum of SOC loss based on 50% reduced carbon inputs for half of the area and SOC loss with no residue removal for the remaining half all expressed in Mg C yr^{-1}. These values were then expressed on a per-hectare basis by dividing by the total area of each county, in which the final difference in SOC loss for the two systems under comparison can be obtained. The average SOC loss expressed in Mg

C ha^{-1} yr^{-1} was also reported for each plant, and converted to its CO_2 equivalence by multiplying by 3.67.

Table 4.14. Soil carbon dynamics and relative SOC loss for the biorefinery at **Adams**: comparison of continuous corn to continuous corn plus 25% residue removal (R1 vs. R3).

Parameters	Units	Gage	Johnson	Nemaha	Pawnee	Richardson
Soil carbon content	g kg^{-1}	11.04	12.23	9.99	12.98	12.6
Soil bulk density	g cm^{-3}	1.61	1.69	1.57	1.66	1.57
Initial SOC, 1/1/2006	Mg C ha^{-1}	53.32	62.01	47.05	64.64	59.35
R1						
Avg. carbon inputs	Mg C ha^{-1}	2.90	2.72	2.94	2.68	3.04
Final SOC, 1/1/2009	Mg C ha^{-1}	51.41	58.77	45.3	60.91	56.35
Δ SOC, 2006-09	Mg C ha^{-1}	-1.91	-3.24	-1.75	-3.73	-3
Δ SOC, 2006-09	Mg C ha^{-1} yr^{-1}	**-0.64**	**-1.08**	**-0.58**	**-1.24**	**-1.00**
Corn hectares	ha	56,980	16,349	30,878	16,484	38,809
Δ SOC, 2006-09	Mg Cyr^{-1}	**-36,277**	**-17,657**	**-18,012**	**-20,495**	**-38,809**
R3:R1						
Avg. carbon inputs	Mg C ha^{-1}	1.68	1.58	1.7	1.55	1.77
Final SOC, 1/1/2009	Mg C ha^{-1}	49.79	57.52	43.96	59.68	54.99
Δ SOC, 2006-09	Mg C ha^{-1}	-3.53	-4.49	-3.09	-4.96	-4.36
Δ SOC, 2006-09	Mg C ha^{-1} yr^{-1}	**-1.18**	**-1.50**	**-1.03**	**-1.65**	**-1.45**
Corn hectares, 50% of residue removed for 50% of area	ha	28,490	8,175	15,439	8,242	19,405
***Δ SOC, 2006-09**	Mg Cyr^{-1}	-33,523	-12,235	-15,902	-13,627	-28,201
Corn hectares, non-residue removal R1 area	ha	28,490	8,175	15,439	8,242	19,405
****Δ SOC, 2006-09**	Mg Cyr^{-1}	-18,139	-8,829	-9,006	-10,248	-19,405
Total Δ SOC, 2006-09	Mg Cyr^{-1}	**-51,662**	**-21,063**	**-24,908**	**-23,875**	**-47,606**
Total Δ SOC, 2006-09	Mg C ha^{-1} yr^{-1}	**-0.91**	**-1.29**	**-0.81**	**-1.45**	**-1.23**
Difference Δ SOC	Mg C ha^{-1} yr^{-1}	**-0.270**	**-0.208**	**-0.223**	**-0.205**	**-0.227**

*ΔSOC is calculated for 50% of area with 50% residue removal. **ΔSOC is calculated for the remaining area with no residue removal.

Total soil carbon loss for the Adams plant under R1 is **131,251** Mg C yr^{-1}
Total soil carbon loss for the Adams plant under R3(R1) is **169,114** Mg C yr^{-1}
Difference in total carbon loss for the Adams plant from residue removal is **37,863** Mg C yr^{-1}
Average soil carbon loss for the Adams plant is **0.227** Mg C ha^{-1} yr^{-1}
Average soil carbon loss on a CO_2 equivalent basis for the Adams plant is **0.831** Mg CO_2e ha^{-1} yr^{-1}

Table 4.15. Soil carbon dynamics and relative SOC loss for the biorefinery at **Adams**: comparison of corn-soybean rotation to continuous corn plus 25% residue removal (R2 vs. R3).

Parameters	**Units**	**Gage**	**Johnson**	**Nemaha**	**Pawnee**	**Richardson**
Soil carbon content	g kg^{-1}	11.04	12.23	9.99	12.98	12.6
Soil bulk density	g cm^{-3}	1.61	1.69	1.57	1.66	1.57
Initial SOC, 1/1/2006	Mg C ha^{-1}	53.32	62.01	47.05	64.64	59.35
R2						
Avg. carbon inputs	Mg C ha^{-1}	2.47	2.22	2.42	2.25	2.61
Final SOC, 1/1/2009	Mg C ha^{-1}	50.71	58.31	44.84	60.52	55.96
Δ SOC, 2006-09	Mg C ha^{-1}	-2.6	-3.7	-2.21	-4.12	-3.39
Δ SOC, 2006-09	Mg C ha^{-1} yr^{-1}	**-0.87**	**-1.23**	**-0.74**	**-1.37**	**-1.13**
Corn hectares	ha	56980	16,349	30,878	16,484	38,809
Δ SOC, 2006-09	Mg Cyr^{-1}	**-49,572**	**-20,164**	**-22,746**	**-22,638**	**-43,855**
R3:R2						
Avg. carbon inputs	Mg C ha^{-1}	1.68	1.58	1.7	1.55	1.77
Final SOC, 1/1/2009	Mg C ha^{-1}	49.79	57.52	43.96	59.68	54.99
Δ SOC, 2006-09	Mg C ha^{-1}	-3.53	-4.49	-3.09	-4.96	-4.36
Δ SOC, 2006-09	Mg C ha^{-1} yr^{-1}	-1.18	-1.50	-1.03	-1.65	-1.45
Corn hectares, 50% of residue removed for 50% of area	ha	28,490	8,175	15,439	8,242	19,405
***Δ SOC, 2006-09**	Mg Cyr^{-1}	-33,523	-12,235	-15,902	-13,627	-28,201
Corn-soybean hectares, non-residue removal R2 area	ha	28,490	8,175	15,439	8,242	19,405
****Δ SOC, 2006-09**	Mg Cyr^{-1}	-24,786	-10,082	-11,373	-11,319	-21,927
Total Δ SOC, 2006-09	Mg Cyr^{-1}	**-58,309**	**-22,317**	**-27,275**	**-24,946**	**-50,129**
Total Δ SOC, 2006-09	Mg C ha^{-1} yr^{-1}	**-1.02**	**-1.37**	**-0.88**	**-1.51**	**-1.29**
Difference Δ SOC	Mg C ha^{-1} yr^{-1}	**-0.153**	**-0.132**	**-0.147**	**-0.140**	**-0.162**

*ΔSOC is calculated for 50% of area with 50% residue removal.
**ΔSOC is calculated for the remaining area with no residue removal.

Total soil carbon loss for the Adams plant under R2 is **158,976** Mg C yr^{-1}
Total soil carbon loss for the Adams plant under R3(R2) is **182,976** Mg C yr^{-1}
Difference in total carbon loss for the Adams plant from residue removal is **24,000** Mg C yr^{-1}
Average soil carbon loss for the Adams plant is **0.147** Mg C ha^{-1} yr^{-1}
Average soil carbon loss on a CO_2 equivalent basis for the Adams plant is **0.538** Mg CO_2e ha^{-1} yr^{-1}

Table 4.16. Soil carbon dynamics and relative SOC loss for the biorefinery at **Norfolk**: comparison of continuous corn to continuous corn plus 25% residue removal (R1 vs. R3).

Parameters	Units	Cuming	Madison	Pierce	Stanton	Wayne
Soil carbon content	g kg^{-1}	14.97	10.81	10.53	10.42	12.18
Soil bulk density	g cm^{-3}	1.49	1.45	1.48	1.42	1.43
Initial SOC, 1/1/2006	Mg C ha^{-1}	66.92	47.02	46.75	44.39	52.25
R1						
Avg. carbon inputs	Mg C ha^{-1}	3.49	3.31	3.51	3.17	3.23
Final SOC, 1/1/2009	Mg C ha^{-1}	64.35	46.29	46.31	43.57	51.16
Δ SOC, 2006-09	Mg C ha^{-1}	-2.57	-0.73	-0.44	-0.82	-1.09
Δ SOC, 2006-09	Mg C ha^{-1} yr^{-1}	**-0.857**	**-0.243**	**-0.147**	**-0.273**	**-0.363**
Corn hectares	ha	63,050	54,511	53,419	33,845	47,240
Δ SOC, 2006-09	Mg Cyr^{-1}	**-54,013**	**-13,264**	**-7,835**	**-9,251**	**-17,164**
R3:R1						
Avg. carbon inputs	Mg C ha^{-1}	2.03	1.92	2.04	1.84	1.87
Final SOC, 1/1/2009	Mg C ha^{-1}	62.72	44.71	44.61	42.1	49.58
Δ SOC, 2006-09	Mg C ha^{-1}	-4.2	-2.31	-2.14	-2.29	-2.67
Δ SOC, 2006-09	Mg C ha^{-1} yr^{-1}	-1.40	-0.770	-0.71	-0.763	-0.89
***Corn hectares, 50% of residue removed for 50% of area**	ha	31,525	27,256	26,709	16,923	23,620
***Δ SOC, 2006-09**	Mg Cyr^{-1}	-44,135	-20,987	-19,053	-12,918	-21,022
****Corn hectares, non-residue removal R1 area**	ha	31,525	27,256	26,709	16,923	23,620
****Δ SOC, 2006-09**	Mg Cyr^{-1}	-27,006	-6,632	-3,917	-4,626	-8,582
Total Δ SOC, 2006-09	Mg Cyr^{-1}	**-71,141**	**-27,619**	**-22,970**	**-17,543**	**-29,604**
Total Δ SOC, 2006-09	Mg C ha^{-1} yr^{-1}	**-1.13**	**-0.51**	**-0.43**	**-0.52**	**-0.63**
Difference Δ SOC	Mg C ha^{-1} yr^{-1}	**-0.272**	**-0.263**	**-0.283**	**-0.245**	**-0.263**

*ΔSOC is calculated for 50% of area with 50% residue removal.
**ΔSOC is calculated for the remaining area with no residue removal.

Total soil carbon loss for the Norfolk plant under R1 is **101,527** Mg C yr^{-1}
Total soil carbon loss for the Norfolk plant under R3(R1) is **168,877** Mg C yr^{-1}
Difference in total carbon loss for the Norfolk plant from residue removal is **67,350** Mg C yr^{-1}
Average soil carbon loss for the Norfolk plant is **0.265** Mg C ha^{-1} yr^{-1}
Average soil carbon loss on a CO_2 equivalent basis for the Norfolk plant is **0.973** Mg CO_2e ha^{-1} yr^{-1}

Table 4.17. Soil carbon dynamics and relative SOC loss for the biorefinery at **Norfolk**: comparison of corn-soybean rotation to continuous corn plus 25% residue removal (R2 vs. R3).

Parameters	Units	Cuming	Madison	Pierce	Stanton	Wayne
Soil carbon content	$g\ kg^{-1}$	14.97	10.81	10.53	10.42	12.18
Soil bulk density	$g\ cm^{-3}$	1.49	1.45	1.48	1.42	1.43
Initial SOC, 1/1/2006	$Mg\ C\ ha^{-1}$	66.92	47.02	46.75	44.39	52.25
R2						
Avg. carbon inputs	$Mg\ C\ ha^{-1}$	2.86	2.71	2.85	2.52	2.62
Final SOC, 1/1/2009	$Mg\ C\ ha^{-1}$	63.77	45.72	45.68	42.97	50.59
Δ SOC, 2006-09	$Mg\ C\ ha^{-1}$	-3.15	-1.3	-1.07	-1.42	-1.66
Δ SOC, 2006-09	$Mg\ C\ ha^{-1}\ yr^{-1}$	**-1.050**	**-0.433**	**-0.357**	**-0.473**	**-0.553**
Corn hectares	ha	63,050	54,511	53,419	33,845	47,240
Δ SOC, 2006-09	$Mg\ Cyr^{-1}$	**-66,203**	**-23,622**	**-19,053**	**-16,020**	**-26,140**
R3:R2						
Avg. carbon inputs	$Mg\ C\ ha^{-1}$	2.03	1.92	2.04	1.84	1.87
Final SOC, 1/1/2009	$Mg\ C\ ha^{-1}$	62.72	44.71	44.61	42.1	49.58
Δ SOC, 2006-09	$Mg\ C\ ha^{-1}$	-4.2	-2.31	-2.14	-2.29	-2.67
Δ SOC, 2006-09	$Mg\ C\ ha^{-1}\ yr^{-1}$	-1.40	-0.77	-0.71	-0.76	-0.89
***Corn hectares, 50% of residue removed for 50% of area**	ha	31525	27256	26709	16923	23620
***Δ SOC, 2006-09**	$Mg\ Cyr^{-1}$	-44,135	-20,987	-19,053	-12,918	-21,022
****Corn-soybean hectares, non-residue removal R2 area**	ha	31,525	27,256	26,709	16,923	23,620
****Δ SOC, 2006-09**	$Mg\ Cyr^{-1}$	-33,101	-11,811	-9,526	-8,010	-13,070
Total Δ SOC, 2006-09	$Mg\ Cyr^{-1}$	**-77,236**	**-32,798**	**-28,579**	**-20,928**	**-34,092**
Total Δ SOC, 2006-09	$Mg\ C\ ha^{-1}\ yr^{-1}$	**-1.23**	**-0.60**	**-0.54**	**-0.62**	**-0.72**
Difference Δ SOC	$Mg\ C\ ha^{-1}\ yr^{-1}$	**-0.175**	**-0.168**	**-0.178**	**-0.145**	**-0.168**

*ΔSOC is calculated for 50% of area with 50% residue removal.
**ΔSOC is calculated for the remaining area with no residue removal.

Total soil carbon loss for the Norfolk plant under R2 is **151,036** $Mg\ C\ yr^{-1}$
Total soil carbon loss for the Norfolk plant under R3(R2) is **193,632** $Mg\ C\ yr^{-1}$
Difference in total carbon loss for the Norfolk plant from residue removal is **42,596** $Mg\ C\ yr^{-1}$
Average soil carbon loss for the Norfolk plant is **0.167** $Mg\ C\ ha^{-1}\ yr^{-1}$
Average soil carbon loss on a CO_2 equivalent basis for the Norfolk plant is **0.612** $Mg\ CO_2e\ ha^{-1}\ yr^{-1}$

Table 4.18. Soil carbon dynamics and relative SOC loss for the biorefinery at **Wood River**: comparison of continuous corn to continuous corn plus 25% residue removal (R1 vs. R3).

Parameters	Units	Buffalo	Hall	Howard	Sherman	Hamilton	Merrick
Soil carbon content	g kg^{-1}	11.57	11.85	11.62	8.75	8.24	10.57
Soil bulk density	g cm^{-3}	1.47	1.48	1.56	1.48	1.57	1.54
Initial SOC, 1/1/2006	Mg C ha^{-1}	51.02	52.61	54.38	38.85	38.81	48.83
R1							
Avg. carbon inputs	Mg C ha^{-1}	3.92	4.03	3.56	3.63	4.13	3.57
Final SOC, 1/1/2009	Mg C ha^{-1}	50.26	51.75	53.04	39.2	39.58	47.94
Δ SOC, 2006-09	Mg C ha^{-1}	-0.760	-0.860	-1.340	0.350	0.770	-0.890
Δ SOC, 2006-09	Mg C ha^{-1} yr^{-1}	**-0.253**	**-0.287**	**-0.447**	**0.117**	**0.257**	**-0.297**
Corn hectares	ha	81,301	77,147	40,657	31,768	81,342	54,997
Δ SOC, 2006-09	Mg Cyr^{-1}	**-20,596**	**-22,115**	**-18,160**	**3,706**	**20,878**	**-16,316**
R3:R1							
Avg. carbon inputs	Mg C ha^{-1}	2.28	2.34	2.07	2.11	2.4	2.07
Final SOC, 1/1/2009	Mg C ha^{-1}	48.47	49.93	51.37	37.48	37.68	46.32
Δ SOC, 2006-09	Mg C ha^{-1}	-2.55	-2.68	-3.01	-1.37	-1.13	-2.51
Δ SOC, 2006-09	Mg C ha^{-1} yr^{-1}	-0.850	-0.893	-1.003	-0.457	-0.377	-0.837
***Corn hectares, 50% of residue removed for 50% of area**	ha	40,651	38,573	20,329	15,884	40,671	27,498
***Δ SOC, 2006-09**	Mg Cyr^{-1}	-34,553	-34,459	-20,396	-7,254	-15,319	-23,007
****Corn hectares, non-residue removal R1 area**	ha	40,651	38,573	20,329	15,884	40,671	27,498
****Δ SOC, 2006-09**	Mg Cyr^{-1}	-10,298	-11,058	-9,080	1,853	10,439	-8,158
Total Δ SOC, 2006-09	Mg Cyr^{-1}	**-44,851**	**-45,516**	**-29,477**	**-5,401**	**-4,881**	**-31,165**
Total Δ SOC, 2006-09	Mg C ha^{-1} yr^{-1}	**-0.55**	**-0.59**	**-0.73**	**-0.17**	**-0.060**	**-0.57**
Difference Δ SOC	Mg C ha^{-1} yr^{-1}	**-0.298**	**-0.303**	**-0.278**	**-0.287**	**-0.317**	**-0.270**

*ΔSOC is calculated for 50% of area with 50% residue removal.
**ΔSOC is calculated for the remaining area with no residue removal.

Total soil carbon loss for the Wood River plant under R1 is **52,604** Mg C yr^{-1}
Total soil carbon loss for the Wood River plant under R3(R1) is **161,290** Mg C yr^{-1}
Difference in total carbon loss for the Wood River plant from removal is **108,686** Mg C yr^{-1}
Average soil carbon loss for the Wood River plant is **0.292** Mg C ha^{-1} yr^{-1}
Average soil carbon loss on a CO_2 equivalent basis for the Wood River plant is **1.07** Mg CO_2e ha^{-1} yr^{-1}

Table 4.19. Soil carbon dynamics and relative SOC loss for the biorefinery at **Wood River**: comparison of corn-soybean rotation to continuous corn plus 25% residue removal (R2 vs. R3).

Parameters	Units	Buffalo	Hall	Howard	Sherman	Hamilton	Merrick
Soil carbon content	g kg^{-1}	11.57	11.85	11.62	8.75	8.24	10.57
Soil bulk density	g cm^{-3}	1.47	1.48	1.56	1.48	1.57	1.54
Initial SOC, 1/1/2006	Mg C ha^{-1}	51.02	52.61	54.38	38.85	38.81	48.83
R2							
Avg. carbon inputs	Mg C ha^{-1}	3.2	3.29	2.94	2.99	3.42	3
Final SOC, 1/1/2009	Mg C ha^{-1}	49.6	51.06	52.46	38.59	38.92	47.4
Δ SOC, 2006-09	Mg C ha^{-1}	-1.42	-1.55	-1.92	-0.26	0.11	-1.43
Δ SOC, 2006-09	Mg C ha^{-1} yr^{-1}	**-0.473**	**-0.517**	**-0.640**	**-0.087**	**0.037**	**-0.477**
Corn hectares	ha	81301	77147	40657	31768	81342	54997
Δ SOC, 2006-09	Mg Cyr^{-1}	**-38,483**	**-39,859**	**-26,021**	**-2,753**	**2,983**	**-26,215**
R3:R2							
Avg. carbon inputs	Mg C ha^{-1}	2.28	2.34	2.07	2.11	2.4	2.07
Final SOC, 1/1/2009	Mg C ha^{-1}	48.47	49.93	51.37	37.48	37.68	46.32
Δ SOC, 2006-09	Mg C ha^{-1}	-2.55	-2.68	-3.01	-1.37	-1.13	-2.51
Δ SOC, 2006-09	Mg C ha^{-1} yr^{-1}	-0.850	-0.893	-1.003	-0.457	-0.377	-0.837
***Corn hectares, 50% of residue removed for 50% of area**	ha	40,651	38,573	20,329	15,884	40,671	27,498
***Δ SOC, 2006-09**	Mg Cyr^{-1}	-34,553	-34,459	-20,396	-7,254	-15,319	-23,007
****Corn-soybean hectares, non-residue removal R2 area**	ha	40,651	38,573	20,329	15,884	40,671	27,498
****Δ SOC, 2006-09**	Mg Cyr^{-1}	-19,241	-19,930	-13,010	-1,377	1,491	-13,108
Total Δ SOC, 2006-09	Mg Cyr^{-1}	**-53,794**	**-54,388**	**-33,407**	**-8,630**	**-13,828**	**-36,115**
Total Δ SOC, 2006-09	Mg C ha^{-1} yr^{-1}	**-0.66**	**-0.71**	**-0.82**	**-0.27**	**-0.17**	**-0.66**
Difference Δ SOC	Mg C ha^{-1} yr^{-1}	**-0.188**	**-0.188**	**-0.182**	**-0.185**	**-0.207**	**-0.180**

*ΔSOC is calculated for 50% of area with 50% residue removal.
**ΔSOC is calculated for the remaining area with no residue removal.

Total soil carbon loss for the Wood River plant under R2 is **120,000** Mg C yr^{-1}
Total soil carbon loss for the Wood River plant under R3(R2) is **200,000** Mg C yr^{-1}
Difference in total carbon loss for the Wood River plant from residue removal is **80,000** Mg Cyr^{-1}
Average soil carbon loss for the Wood River plant is **0.188** Mg C ha^{-1} yr^{-1}
Average soil carbon loss on a CO_2 equivalent basis for the Wood River plant is **0.691** Mg CO_2e ha^{-1} yr^{-1}

Crop residue removal nitrogen dynamics

Determining nitrogen content and N_2O emissions from residue removal

Because crop residue removal reduces the soil nitrogen content and decreases the release of N_2O to the atmosphere, the impact of nitrogen dynamics on GHG intensity should be accounted for and included in GHG emission in LCA. This is particularly important as N2O emissions have been shown to be relatively large fraction of life cycle emissions; also generally associated with substantial uncertainties (Mosier et al. 2009). In this section, we estimated the change in soil nitrogen from residue and its conversion into N_2O (e.g. and CO_2e) for all counties at the three biorefineries. Similar to the soil carbon analysis presented previously, we compared systems with continuous corn to continuous corn plus 25% residue removal (R1 vs. R3); and systems with corn-soybean rotation to continuous corn plus 25% residue removal (R2 vs. R3). Parameters used in the calculations for nitrogen content and N_2O emissions from corn and soybean were taken from the 2006 IPCC guidelines for National Greenhouse Gas Inventories (IPCC 2006), and shown in **Table 4.20**. A summary of nitrogen dynamics for the three biorefineries under a reference and a biomass removal system is provided in **Tables 4.21-4.22**. As expected, there was a reduction in soil nitrogen levels and N_2O emissions for the three plants under both systems (R1 vs. R3 & R2 vs. R3) as a result of residue removal.

Table 4.20. Parameters for calculating nitrogen content and N_2O emissions from corn and soybean (IPCC, 2006).

Parameter values	Parameters for estimating nitrogen contents
	Corn
0.006	N content of above ground residues, N_{AG}
0.007	N content of below ground residues, N_{BG}
0.01	Emission factor for N additions from crop residues due to soil carbon loss [kg N_2O-N (kg N)$^{-1}$]
	Soybean
0.008	N content of above ground residues, N_{AG}
0.008	N content of below ground residue, N_{BG}
0.01	Emission factor for N additions from crop residues due to soil carbon loss [kg N_2O-N (kg N)$^{-1}$]

Table 4.21. Summary of nitrogen content and N_2O emissions for the three biorefineries under systems R1 vs. R3.

Plant	Adams	Norfolk	Wood River	Average
ΔN_2O-N (Mg N_2O-N ha^{-1} yr^{-1})	-8.99E-05	-1.05E-04	-1.20E-04	-1.05E-04
ΔN_2O (Mg N_2O ha^{-1} yr^{-1})	-0.00014	-0.00017	-0.00019	-0.00017

Table 4.22. Summary of nitrogen content and N_2O emissions for the three biorefineries under systems R2 vs. R3.

Plant	Adams	Norfolk	Wood River	Average
ΔN_2O-N (Mg N_2O-N ha^{-1} yr^{-1})	-6.81E-05	-7.33E-05	-8.64E-05	-7.59E-05
ΔN_2O (Mg N_2O ha^{-1} yr^{-1})	-0.00011	-0.00012	-0.00014	-0.00012

To calculate soil nitrogen expressed as N_2O-N, nitrogen content contained in the aboveground residue and root biomass were each estimated using parameter values from Tables 4.2 and 4.20. In calculating N_2O-N present in the root biomass for corn, root biomass given as Mg C ha^{-1} (from Tables 4.4-4.6) were first converted to its equivalent dry matter mass in Mg ha^{-1} by dividing by 40% and 66% from Table 4.2. This value was then multiplied by 0.007 and 0.01 from Table 4.2 to give the N_2O-N from root biomass. The first step of the calculations described was omitted in estimating N_2O-N for soybean since the dry matter mass of its aboveground residue and root biomass was already provided in Table 4.7. The conversion of N_2O-N to GHG N_2O was done by multiplying the first term by 44/28 (mass of N_2O per mass of N_2). Given the Global Warming Potential (GWP) for N_2O, the CO_2e for this GHG gas was determined by multiplying by 298.

Following the calculation methods described above, the difference in total N inputs, and their conversion into N_2O, CO_2 equivalent, and CO_2 equivalent C from 25% residue removal for the three plants under system R1 vs. R3 are shown (**Tables 4.23-4.25)**. Similar calculations were carried out for soybean for the corn-soybean rotation system R2 (**Tables 4.26-4.29)**. To analyze nitrogen dynamics for the system with continuous corn plus 25% residue removal (R3), change in soil nitrogen expressed in CO_2e-C with the unit of Mg CO_2e-C yr^{-1} was calculated as the sum of change in nitrogen based on 50% residue removal on half of the area plus change in nitrogen with no removal on the remaining half (average values on removal areas were divided by 2 to determine average loss on total crop acres). These values were expressed on a per hectare basis by dividing by the total area of each county, in which the final difference in soil nitrogen under system R2 vs. R3 were obtained (**Tables 4.30-4.32)**.

Table 4.23. The difference in total soil N inputs from aboveground residue and root biomass, and their conversion into N_2O, CO_2 equivalent, and CO_2 equivalent C under 25% residue removal in surrounding counties at the **Adams** plant from 2006 to 2008 (R1 vs. R3).

County	year	ΔN_2O-N in aboveground residue Mg/ha/yr	ΔN_2O Mg/ha/yr	ΔCO_2e Mg/ha/yr	average ΔCO_2e Mg/ha/yr	ΔCO_2e-C Mg/ha/yr	average ΔCO_2e-C Mg/ha/yr
Gage	2006	-0.000185	-0.000291	-0.087		-0.024	
Gage	2007	-0.000165	-0.000259	-0.077		-0.021	
Gage	2008	-0.000199	-0.000312	-0.093	-0.086	-0.025	-0.023
Johnson	2006	-0.000146	-0.000229	-0.068		-0.019	
Johnson	2007	-0.000185	-0.000291	-0.087		-0.024	
Johnson	2008	-0.000183	-0.000288	-0.086	-0.080	-0.023	-0.022
Nemaha	2006	-0.000153	-0.000240	-0.072		-0.020	
Nemaha	2007	-0.000201	-0.000316	-0.094		-0.026	
Nemaha	2008	-0.000201	-0.000316	-0.094	-0.087	-0.026	-0.024
Pawnee	2006	-0.000149	-0.000233	-0.070		-0.019	
Pawnee	2006	-0.000171	-0.000269	-0.080		-0.022	
Pawnee	2006	-0.000186	-0.000292	-0.087	-0.079	-0.024	-0.022
Richardson	2006	-0.000190	-0.000299	-0.089		-0.024	
Richardson	2007	-0.000186	-0.000292	-0.087		-0.024	
Richardson	2008	-0.000198	-0.000312	-0.093	-0.090	-0.025	-0.024

Average change in N_2O-N for the **Adams plant** is **-8.99E-05** Mg N_2O-N ha^{-1} yr^{-1}
Average change in N_2O for the **Adams plant** is **-0.00014** Mg N_2O ha^{-1} yr^{-1}
Average change in CO_2e for the **Adams plant** is **-0.042** Mg CO_2e ha^{-1} yr^{-1}

Table 4.24. The difference in total N inputs in aboveground residue and root biomass, and their conversion into N_2O, CO_2 equivalent, and CO_2 equivalent C basis under 25% residue removal in surrounding counties at the **Norfolk** plant from 2006 to 2008 (R1 vs. R3).

County	Year	ΔN_2O-N in aboveground residue Mg/ha/yr	ΔN_2O Mg/ha/yr	ΔCO_2e Mg/ha/yr	Average ΔCO2e Mg/ha/yr	ΔCO_2e-C Mg/ha/yr	Average ΔCO_2e-C Mg/ha/yr
Cuming	2006	-0.000205	-0.000322	-0.096		-0.026	
Cuming	2007	-0.000228	-0.000359	-0.107		-0.029	
Cuming	2008	-0.000226	-0.000356	-0.106	-0.103	-0.029	-0.028
Madison	2006	-0.000199	-0.000313	-0.093		-0.025	
Madison	2007	-0.000215	-0.000338	-0.101		-0.027	
Madison	2008	-0.000212	-0.000333	-0.099	-0.098	-0.027	-0.027
Pierce	2006	-0.000200	-0.000314	-0.094		-0.026	
Pierce	2007	-0.000221	-0.000347	-0.103		-0.028	
Pierce	2008	-0.000242	-0.000380	-0.113	-0.103	-0.031	-0.028
Stanton	2006	-0.000173	-0.000272	-0.081		-0.022	
Stanton	2007	-0.000225	-0.000354	-0.105		-0.029	
Stanton	2008	-0.000201	-0.000316	-0.094	-0.094	-0.026	-0.026
Wayne	2006	-0.000155	-0.000243	-0.073		-0.020	
Wayne	2007	-0.000219	-0.000344	-0.102		-0.028	
Wayne	2008	-0.000236	-0.000371	-0.111	-0.095	-0.030	-0.026

Average change in N_2O-N for the **Norfolk plant** is **-1.05E-04** Mg N_2O-N ha^{-1} yr^{-1}
Average change in N_2O for the **Norfolk plant** is **-0.00017** Mg N_2O ha^{-1} yr^{-1}
Average change in CO_2e for the **Norfolk plant** is **-0.049** Mg CO_2e ha^{-1} yr^{-1}

Table 4.25. The difference in total N inputs in aboveground residue and root biomass, and their conversion into N_2O, CO_2 equivalent, and CO_2 equivalent C basis under 25% residue removal in surrounding counties at the **Wood River** plant from 2006 to 2008 (R1 v s. R3)

County	Year	ΔN_2O-N in aboveground residue Mg/ha/yr	ΔN_2O Mg/ha/yr	ΔCO_2e Mg/ha/yr	Average ΔCO2e Mg/ha/yr	ΔCO_2e-C Mg/ha/yr	Average ΔCO_2e-C Mg/ha/yr
Buffalo	2006	-0.000248	-0.000390	-0.116		-0.032	
Buffalo	2007	-0.000249	-0.000391	-0.117		-0.032	
Buffalo	2008	-0.000244	-0.000383	-0.114	-0.116	-0.031	-0.032
Hall	2006	-0.000260	-0.000409	-0.122		-0.033	
Hall	2007	-0.000260	-0.000408	-0.122		-0.033	
Hall	2008	-0.000241	-0.000379	-0.113	-0.119	-0.031	-0.032
Howard	2006	-0.000220	-0.000346	-0.103		-0.028	
Howard	2007	-0.000221	-0.000347	-0.104		-0.028	
Howard	2008	-0.000231	-0.000363	-0.108	-0.105	-0.030	-0.029
Sherman	2006	-0.000216	-0.000340	-0.101		-0.028	
Sherman	2007	-0.000230	-0.000362	-0.108		-0.029	
Sherman	2008	-0.000239	-0.000376	-0.112	-0.107	-0.031	-0.029
Hamilton	2006	-0.000257	-0.000404	-0.120		-0.033	
Hamilton	2007	-0.000253	-0.000397	-0.118		-0.032	
Hamilton	2008	-0.000271	-0.000425	-0.127	-0.122	-0.035	-0.033
Merrick	2006	-0.000241	-0.000379	-0.113		-0.031	
Merrick	2007	-0.000216	-0.000340	-0.101		-0.028	
Merrick	2008	-0.000217	-0.000341	-0.101	-0.105	-0.028	-0.029

Average change in N_2O-N for the **Wood River plant** is **-1.2E-04** Mg N_2O-N ha^{-1} yr^{-1}
Average change in N_2O for the **Wood River plant** is **-0.00019** Mg N_2O ha^{-1} yr^{-1}
Average change in CO_2e for the **Wood River plant** is **-0.056** Mg CO_2e ha^{-1} yr^{-1}

Table 4.26. Total N inputs in aboveground residue and root biomass, and their conversion into N_2O, CO_2 equivalent, and CO_2 equivalent C basis for soybean in all counties in 2007. Nitrogen contents are calculated based on parameters in Tables 2 &20.

County	N_2O-N in aboveground residue Mg/ha/yr	N_2O-N in root biomass Mg/ha/yr	Total N_2O-N Mg/ha/yr	total N_2O Mg/ha/yr	CO_2e Mg/ha/yr	CO_2e-C Mg/ha/yr
Gage	0.000223	5.78E-05	0.000281	0.000441	0.132	0.036
Johnson	0.000245	6.34E-05	0.000308	0.000484	0.144	0.039
Nemaha	0.000282	7.31E-05	0.000355	0.000558	0.166	0.045
Pawnee	0.000248	6.42E-05	0.000312	0.000490	0.146	0.040
Richardson	0.000280	7.27E-05	0.000353	0.000555	0.165	0.045
Cuming	0.000298	7.74E-05	0.000376	0.000590	0.176	0.048
Madison	0.000276	7.15E-05	0.000347	0.000546	0.163	0.044
Pierce	0.000262	6.80E-05	0.000330	0.000519	0.155	0.042
Stanton	0.000275	7.12E-05	0.000346	0.000544	0.162	0.044
Wayne	0.000282	7.31E-05	0.000355	0.000558	0.166	0.045
Buffalo	0.000307	7.95E-05	0.000386	0.000607	0.181	0.049
Hall	0.000323	8.38E-05	0.000407	0.000639	0.191	0.052
Howard	0.000282	7.32E-05	0.000356	0.000559	0.167	0.045
Sherman	0.000293	7.61E-05	0.000369	0.000581	0.173	0.047
Hamilton	0.000320	8.31E-05	0.000403	0.000634	0.189	0.052
Merrick	0.000293	7.59E-05	0.000369	0.000580	0.173	0.047

Table 4.27. Total N inputs in aboveground residue and root biomass, and their conversion into N_2O, CO_2 equivalent, and CO_2 equivalent C basis for system R2 in surrounding counties at the **Adams** plant from 2006 to 2008. Nitrogen contents are calculated based on parameters in Tables 2 & 20.

County	Year	Crop	N_2O-N in above-ground residue Mg/ha	N_2O-N in root biomass Mg/ha	Total N_2O-N Mg/ha	Total N_2O Mg/ha	CO_2e Mg/ha	CO_2e-C Mg/ha
Gage	2006	corn	0.00037	1.25E-04	0.00050	0.00078	0.232	0.063
Gage	2007	soybean	0.00022	5.78E-05	0.00028	0.00044	0.132	0.036
Gage	2008	corn	0.00040	1.34E-04	0.00053	0.00083	0.249	0.068
Johnson	2006	corn	0.00029	9.88E-05	0.00039	0.00061	0.183	0.050
Johnson	2007	soybean	0.00024	6.34E-05	0.00031	0.00048	0.144	0.039
Johnson	2008	corn	0.00037	1.24E-04	0.00049	0.00077	0.229	0.063
Nemaha	2006	corn	0.00031	1.03E-04	0.00041	0.00064	0.192	0.052
Nemaha	2007	soybean	0.00028	7.31E-05	0.00035	0.00056	0.166	0.045
Nemaha	2008	corn	0.00040	1.36E-04	0.00054	0.00084	0.252	0.069
Pawnee	2006	corn	0.00030	1.01E-04	0.00040	0.00062	0.186	0.051
Pawnee	2007	soybean	0.00025	6.42E-05	0.00031	0.00049	0.146	0.040
Pawnee	2008	corn	0.00037	1.26E-04	0.00050	0.00078	0.233	0.064
Richardson	2006	corn	0.00038	1.29E-04	0.00051	0.00080	0.239	0.065
Richardson	2007	soybean	0.00028	7.27E-05	0.00035	0.00055	0.165	0.045
Richardson	2008	corn	0.00040	1.34E-04	0.00053	0.00083	0.249	0.068

Table 4.28. Total N inputs in aboveground residue and root biomass, and their conversion into N_2O, CO_2 equivalent, and CO_2 equivalent C basis for system R2 in surrounding counties at the **Norfolk** plant from 2006 to 2008. Nitrogen contents are calculated based on parameters in Tables 2 & 20.

County	Year	Crop	N_2O-N in above-ground residue Mg/ha	N_2O-N in root biomass Mg/ha	Total N_2O-N Mg/ha	Total N_2O Mg/ha	CO_2e Mg/ha	CO_2e-C Mg/ha
Cuming	2006	corn	0.00041	1.38E-04	0.00055	0.00086	0.257	0.070
Cuming	2007	soybean	0.00030	7.74E-05	0.00038	0.00059	0.176	0.048
Cuming	2008	corn	0.00045	1.53E-04	0.00061	0.00095	0.284	0.077
Madison	2006	corn	0.00040	1.35E-04	0.00053	0.00084	0.249	0.068
Madison	2007	soybean	0.00028	7.15E-05	0.00035	0.00055	0.163	0.044
Madison	2008	corn	0.00042	1.43E-04	0.00057	0.00089	0.265	0.072
Pierce	2006	corn	0.00040	1.35E-04	0.00054	0.00084	0.251	0.068
Pierce	2007	soybean	0.00026	6.80E-05	0.00033	0.00052	0.155	0.042
Pierce	2008	corn	0.00048	1.64E-04	0.00065	0.00102	0.303	0.083
Stanton	2006	corn	0.00035	1.17E-04	0.00046	0.00073	0.217	0.059
Stanton	2007	soybean	0.00027	7.12E-05	0.00035	0.00054	0.162	0.044
Stanton	2008	corn	0.00040	1.36E-04	0.00054	0.00085	0.252	0.069
Wayne	2006	corn	0.00031	1.05E-04	0.00041	0.00065	0.194	0.053
Wayne	2007	soybean	0.00028	7.31E-05	0.00035	0.00056	0.166	0.045
Wayne	2008	corn	0.00047	1.60E-04	0.00063	0.00099	0.296	0.081

Table 4.29. Total N inputs in aboveground residue and root biomass, and their conversion into N_2O, CO_2 equivalent, and CO_2 equivalent C basis for system R2 in surrounding counties at the **Wood River** plant from 2006 to 2008. Nitrogen contents are calculated based on parameters in Tables 2 & 20.

County	Year	Crop	N_2O-N in aboveground residue Mg/ha	N_2O-N in root biomass Mg/ha	Total N_2O-N Mg/ha	Total N_2O Mg/ha	CO_2e Mg/ha	CO_2e-C Mg/ha
Buffalo	2006	corn	0.00050	1.68E-04	0.00066	0.00104	0.311	0.085
Buffalo	2007	soybean	0.00031	7.95E-05	0.00039	0.00061	0.181	0.049
Buffalo	2008	corn	0.00049	1.65E-04	0.00065	0.00103	0.306	0.083
Hall	2006	corn	0.00052	1.76E-04	0.00070	0.00109	0.326	0.089
Hall	2007	soybean	0.00032	8.38E-05	0.00041	0.00064	0.191	0.052
Hall	2008	corn	0.00048	1.63E-04	0.00065	0.00102	0.303	0.083
Howard	2006	corn	0.00044	1.49E-04	0.00059	0.00093	0.276	0.075
Howard	2007	soybean	0.00028	7.32E-05	0.00036	0.00056	0.167	0.045
Howard	2008	corn	0.00046	1.56E-04	0.00062	0.00097	0.290	0.079
Sherman	2006	corn	0.00043	1.46E-04	0.00058	0.00091	0.271	0.074
Sherman	2007	soybean	0.00029	7.61E-05	0.00037	0.00058	0.173	0.047
Sherman	2008	corn	0.00048	1.62E-04	0.00064	0.00101	0.300	0.082
Hamilton	2006	corn	0.00051	1.74E-04	0.00069	0.00108	0.322	0.088
Hamilton	2007	soybean	0.00032	8.31E-05	0.00040	0.00063	0.189	0.052
Hamilton	2008	corn	0.00054	1.83E-04	0.00072	0.00114	0.339	0.093
Merrick	2006	corn	0.00048	1.63E-04	0.00065	0.00102	0.303	0.083
Merrick	2007	soybean	0.00029	7.59E-05	0.00037	0.00058	0.173	0.047
Merrick	2008	corn	0.00043	1.47E-04	0.00058	0.00091	0.272	0.074

Table 4.30. The difference in total N inputs in aboveground residue and root biomass, and their conversion into N_2O, CO_2 equivalent, and CO_2 equivalent C under 25% residue removal in surrounding counties at the **Adams** plant from 2006 to 2008 (R2 vs. R3).

Parameters	**Units**	**Gage**	**Johnson**	**Nemaha**	**Pawnee**	**Richardson**
R2						
Average N_2O-N, 2006-08	Mg N_2O-N ha^{-1} yr^{-1}	0.00044	0.00040	0.00043	0.00040	0.00046
Average N_2O, 2006-08	Mg N_2O ha^{-1} yr^{-1}	0.00068	0.00062	0.00068	0.00063	0.00073
Average CO_2e, 2006-08	Mg CO_2e ha^{-1} yr^{-1}	0.204	0.186	0.203	0.188	0.217
Average CO_2e-C, 2006-08	Mg CO_2e-C ha^{-1} yr^{-1}	0.056	0.051	0.055	0.051	0.059
Corn hectares	ha	56980	16,349	30,878	16,484	38,809
Average CO_2e-C, 2006-08	Mg CO_2e-C yr^{-1}	**3,171**	**827**	**1,711**	**847**	**2,302**
R3:R2						
Average N_2O-N, 2006-08	Mg N_2O-N ha^{-1} yr^{-1}	0.00031	0.00029	0.00031	0.00028	0.00032
Average N_2O, 2006-08	Mg N_2O ha^{-1} yr^{-1}	0.00048	0.00045	0.00049	0.00044	0.00050
Average CO_2e, 2006-08	Mg CO_2e ha^{-1} yr^{-1}	0.144	0.135	0.145	0.132	0.150
Average CO_2e-C, 2006-08	Mg CO_2e-C ha^{-1} yr^{-1}	0.039	0.037	0.040	0.036	0.041
***Corn hectares, 50% of residue removed for 50% of area**	ha	28,490	8,175	15,439	8,242	19,405
***Average CO_2e-C, 2006-08**	Mg CO_2e-C yr^{-1}	1,115	300	611	297	796
Corn-soybean hectares, non-residue removal R2 area	ha	28,490	8,175	15,439	8,242	19,405
****Average CO_2e-C, 2006-08**	Mg CO_2e-C yr^{-1}	1,586	414	855	424	1,151
Total average CO_2e-C, 2006-08	Mg CO_2e-C yr^{-1}	**2,701**	**714**	**1,467**	**721**	**1,947**
Total average CO_2e-C, 2006-08	Mg CO_2e-C ha^{-1} yr^{-1}	**0.047**	**0.044**	**0.047**	**0.044**	**0.05**
ΔCO_2e-C, 2006-08	Mg CO_2e-C ha^{-1} yr^{-1}	**-0.008**	**-0.007**	**-0.008**	**-0.008**	**-0.009**

Average change in N_2O-N for the **Adams plant** is **-6.81E-05** Mg N_2O-N ha^{-1} yr^{-1}
Average change in N_2O for the **Adams plant** is **-0.00011** Mg N_2O ha^{-1} yr^{-1}
Average change in CO_2e for the **Adams plant** is **-0.032** Mg CO_2e ha^{-1} yr^{-1}

Table 4.31. The difference in total N inputs in aboveground residue and root biomass, and their conversion into N_2O, CO_2 equivalent, and CO_2 equivalent C under 25% residue removal in surrounding counties at the **Norfolk** plant from 2006 to 2008 (R2 vs. R3).

Parameters	Units	Cuming	Madison	Pierce	Stanton	Wayne
R2						
Average N_2O-N, 2006-08	Mg N_2O-N ha^{-1} yr^{-1}	0.00051	0.00048	0.00050	0.00045	0.00047
Average N_2O, 2006-08	Mg N_2O ha^{-1} yr^{-1}	0.00080	0.00076	0.00079	0.00071	0.00073
Average CO_2e, 2006-08	Mg CO_2e ha^{-1} yr^{-1}	0.239	0.226	0.236	0.210	0.219
Average CO_2e-C, 2006-08	Mg CO_2e-C ha^{-1} yr^{-1}	0.065	0.062	0.064	0.057	0.060
Corn hectares	ha	63050	54,511	53,419	33,845	47,240
Average CO_2e-C, 2006-08	Mg CO_2e-C yr^{-1}	**4,105**	**3,357**	**3,441**	**1,942**	**2,819**
R3:R2						
Average N_2O-N, 2006-08	Mg N_2O-N ha^{-1} yr^{-1}	0.00037	0.00035	0.00037	0.00034	0.00034
Average N_2O, 2006-08	Mg N_2O ha^{-1} yr^{-1}	0.00058	0.00055	0.00058	0.00053	0.00054
Average CO_2e, 2006-08	Mg CO_2e ha^{-1} yr^{-1}	0.173	0.164	0.173	0.157	0.160
Average CO_2e-C, 2006-08	Mg CO_2e-C ha^{-1} yr^{-1}	0.047	0.045	0.047	0.043	0.044
***Corn hectares, 50% of residue removed for 50% of area**	ha	31,525	27,256	26,709	16,923	23,620
***Average CO_2e-C, 2006-08**	Mg CO_2e-C yr^{-1}	1,483	1,218	1,264	724	1,028
****Corn-soybean hectares, non-residue removal R2 area**	ha	31,525	27,256	26,709	16,923	23,620
****Average CO_2e-C, 2006-08**	Mg CO_2e-C yr^{-1}	2,053	1,678	1,721	971	1,409
Total average CO_2e-C, 2006-08	Mg CO_2e-C yr^{-1}	**3,536**	**2,896**	**2,984**	**1,695**	**2,437**
Total average CO_2e-C, 2006-08	Mg CO_2e-C ha^{-1} yr^{-1}	**0.056**	**0.053**	**0.056**	**0.050**	**0.05**
ΔCO_2e-C, 2006-08	Mg CO_2e-C ha^{-1} yr^{-1}	**-0.009**	**-0.008**	**-0.009**	**-0.007**	**-0.008**

Average change in N_2O-N for the **Norfolk plant** is **-7.33E-05** Mg N_2O-N ha^{-1} yr^{-1}
Average change in N_2O for the **Norfolk plant** is **-0.00012** Mg N_2O ha^{-1} yr^{-1}
Average change in CO_2e for the **Norfolk plant** is **-0.034** Mg CO_2e ha^{-1} yr^{-1}

Table 4.32. The difference in total N inputs in aboveground residue and root biomass, and their conversion into N_2O, CO_2 equivalent, and CO_2 equivalent C under 25% residue removal in surrounding counties at the **Wood River** plant from 2006 to 2008 (R2 vs. R3).

Parameters	Units	Buffalo	Hall	Howard	Sherman	Hamilton	Merrick
R2							
Average N_2O-N, 2006-08	Mg N_2O-N ha^{-1} yr^{-1}	0.00057	0.00058	0.00052	0.00053	0.00061	0.00053
Average N_2O, 2006-08	Mg N_2O ha^{-1} yr^{-1}	0.00089	0.00092	0.00082	0.00083	0.00095	0.00084
Average CO_2e, 2006-08	Mg CO_2e ha^{-1} yr^{-1}	0.266	0.273	0.244	0.248	0.283	0.249
Average CO_2e-C, 2006-08	Mg CO_2e-C ha^{-1} yr^{-1}	0.073	0.074	0.067	0.068	0.077	0.068
Corn hectares	ha	81,301	77,147	40,657	31,768	81,342	54997
Average CO_2e-C, 2006-08	Mg CO_2e-C yr^{-1}	**5,895**	**5,745**	**2,707**	**2,149**	**6,287**	**3,735**
R3:R2							
Average N_2O-N, 2006-08	Mg N_2O-N ha^{-1} yr^{-1}	0.00041	0.00043	0.00038	0.00038	0.00044	0.00038
Average N_2O, 2006-08	Mg N_2O ha^{-1} yr^{-1}	0.00065	0.00067	0.00059	0.00060	0.00069	0.00059
Average CO_2e, 2006-08	Mg CO_2e ha^{-1} yr^{-1}	0.194	0.199	0.176	0.180	0.204	0.177
Average CO_2e-C, 2006-08	Mg CO_2e-C ha^{-1} yr^{-1}	0.053	0.054	0.048	0.049	0.056	0.048
***Corn hectares, 50% of residue removed for 50% of area**	ha	40,651	38,573	20,329	15,884	40,671	27498
***Average CO_2e-C, 2006-08**	Mg CO_2e-C yr^{-1}	2,150	2,096	976	778	2,265	1,324
****Corn-soybean hectares, non-residue removal R2 area**	ha	40,651	38,573	20,329	15,884	40,671	27,498
****Average CO_2e-C, 2006-08**	Mg CO_2e-C yr^{-1}	2,947	2,873	1,354	1,075	3,144	1,867
Total average CO_2e-C, 2006-08	Mg CO_2e-C yr^{-1}	**5,097**	**4,968**	**2,330**	**1,852**	**5,409**	**3,191**
Total average CO_2e-C, 2006-08	Mg CO_2e-C ha^{-1} yr^{-1}	**0.063**	**0.06**	**0.06**	**0.06**	**0.07**	**0.06**
ΔCO_2e-C, 2006-08	Mg CO_2e-C ha^{-1} yr^{-1}	**-0.010**	**-0.010**	**-0.009**	**-0.009**	**-0.011**	**-0.010**

Average change in N_2O-N for the **Wood River plant** is **-8.64E-05** Mg N_2O-N ha^{-1} yr^{-1}
Average change in N_2O for the **Wood River plant** is **-0.00014** Mg N_2O ha^{-1} yr^{-1}
Average change in CO_2e for the **Wood River plant** is **-0.040** Mg CO_2e ha^{-1} yr^{-1}

Switchgrass Systems

Detailed investigations of SOC dynamics associated with annually harvested switchgrass are limited to only a few studies. Where switchgrass was grown and annually harvested in Alabama, experiments showed no significant sequestration of SOC in less than three years compared to pasture (Bransby et al., 1998) or fallow (Ma et al., 2000). Levels of SOC were also not responsive to differences in N rate, cultivar, row spacing, or harvest frequency (Ma et al., 2000). Compared to row crops, switchgrass did gain SOC, but was only shown to increase net SOC over 10 years by 45% and 28% at depths of 0-15 cm, and 15-30 cm, respectively. In the southern US, low carbon sequestration is due to relatively higher moisture and higher temperatures compared to the northern U.S.

In Pennsylvania in the eastern U.S, a recent studied showed that SOC decreased under continual harvest of grasslands over eight years (Skinner 2008).

In cooler and dryer climates, a number of studies have found measurable C sequestration under harvested perennial grasses. After annual repeated harvests in Quebec, SOC levels under switchgrass increased compared to maize (Zan et al., 2001). After four years of annual harvests in North Dakota, the highest reported C sequestration rate was 10.1 Mg C ha^{-1} yr^{-1} (Frank et al., 2004). On the low side, Miscanthus sp. (a species similar to switchgrass) in Ireland was found to sequester SOC at 0.6 Mg C ha^{-1} yr^{-1} (Clifton-Brown et al., 2007).

In a more recent study, analysis of changes in SOC under harvested switchgrass was not conducted on a constant soil mass basis (Liebig et al. 2008); similar to Frank et al. (2004). Measurement on a constant depth basis (instead of constant mass) appears to have introduced substantial error and undermined the validity of those results (personal communication, Professor Kenneth G. Cassman; Gifford and Roderick 2003; VandenBygaart 2006). Due to limited accurate regional data and associated models (Lee et al. 2007), the substantial uncertainty surrounding changes in SOC under harvested switchgrass in Nebraska does not enable a confident estimation for LCA at this time; this report does not include any modeled calculations for switchgrass.

4.2 LCA of Biomass-Powered CHP Biorefinery

In part I, we used the DK model to estimate SOC loss from crop residue removal on a county-level basis in three biomass production regions for CHP. Based on the SOC data, soil nitrogen and N_2O emissions were also estimated using parameter values extracted from the 2006 IPCC guidelines. A summary of our part I analysis for both a reference (R1 or R2) and a biomass removal system (R3) is provided (**Tables 4.33-4.34)**. Because SOC losses were predicted in all three regions, they were given positive signs when expressed as CO_2 equivalents to signify positive CO_2 emissions. Nitrogen contents in CO_2 equivalent were assigned negative signs since less N_2O was released into the atmosphere as a result of residue removal, thus helping to reduce the GHG intensity in this analysis.

Table 4.33. Summary of analysis in Part I showing the impact of crop residue removal on SOC and N_2O-N dynamics expressed as CO_2 equivalents for the three biorefineries under system R1 vs. R3.

	Mg $CO_2e\ ha^{-1}\ yr^{-1}$			
Plant	**Adams**	**Norfolk**	**Wood River**	***Average***
SOC	0.831	0.973	1.07	0.958
N_2O	-0.042	-0.050	-0.056	-0.049
Total CO_2e	**0.789**	**0.924**	**1.01**	**0.909**

Table 4.34. Summary of analysis in Part I showing the impact of crop residue removal on SOC and N_2O-N dynamics expressed as CO_2 equivalents for the three biorefineries under system R2 vs. R3.

	Mg $CO_2e\ ha^{-1}\ yr^{-1}$			
Plant	**Adams**	**Norfolk**	**Wood River**	***Average***
SOC	0.538	0.612	0.691	0.614
N_2O	-0.032	-0.034	-0.040	-0.035
Total CO_2e	**0.506**	**0.578**	**0.651**	**0.578**

GREET model application

In this part of analysis, we constructed an LCA for the corn ethanol system for the three biomass-powered biorefineries using the CA-GREET model used the California Air Resources Board (CARB) for its Low Carbon Fuel Standard (**Table 4.35**). (We could not recreate EPA's methods because of their relative complexity.) Specifically, we modeled systems with 100% biomass-CHP and 100% biomass-CHP plus our SOC and N_2O corrected results. Below, we only incorporated data from systems with continuous corn to continuous corn plus 25% residue removal (R1 vs. R3) into the LCA because they are consistent with the economic report. Results from systems with corn-soybean rotation to continuous corn plus 25% residue removal (R2 vs. R3) are not shown here, but they were estimated above because they represent more realistic changes from current practices to residue removal; and will be presented in future analysis. First, we established baseline systems for gasoline, and corn ethanol with and without CHP by determining their GHG intensities using the model. We then checked these values with those produced for the same systems in the CARB lookup table to make sure they were identical. This step was necessary to ensure validity of our results.

The full fuel cycle in the CA-GREET model consists of GHG emissions from two main components: Well-to-Tank (WTT) and ethanol combustion, both of which can be expressed as GHG emission in g $mmBtu^{-1}$ or g MJ^{-1}. To reproduce the GHG intensity in $gCO_2e\ MJ^{-1}$ for a dry mill corn ethanol system with dry DGS, 80% NG and 20% biomass in

Midwest, we first select the appropriate region from the pull-down menu in the "Regional LT" tab in the model. We then adjust the parameters in Section 7.9.c.2 in the "Inputs" tab for shares of NG, coal, and corn stover to their appropriate percentages (80%, 0%, and 20%, respectively). We also made sure that the share of corn ethanol plant types is 100% for a dry mill plant. After these adjustments were made, the "Results" tab provides the GHGs reading from the column labeled as "Dedi. EtOH vehicle: E100, corn dry". This is the value for WTT in g $mmBtu^{-1}$. The value for ethanol combustion can be found in the "Fuel_Specs" tab for Biogenic Carbon in Fuel in g $mmBtu^{-1}$. The sum of these two values is the GHG intensity for the system described. Dividing this number by 1055.055 converts it to $gCO_2e\ MJ^{-1}$ (Table 35).

To correct for SOC and N_2O-N for a dry mill corn ethanol system with dry DGS and 100% biomass, we first converted average CO_2e for system R1 vs. R3 (0.909 Mg $CO_2e\ ha^{-1}\ yr^{-1}$ from Table 33) to the unit of $gCO_2e\ MJ^{-1}$. The following conversion method was used:

(0.909 Mg $CO_2e\ ha^{-1}\ yr^{-1}$)*(1,000,000 g/Mg) = 909,000 g $CO_2e\ ha^{-1}\ yr^{-1}$

(158 bu/acre)*(2.72 gal/bu)*(2.471 acre/ha) = 1061.93 gal/ha

(1061.93 gal/ha)*(80.5 MJ/gal) = 85515.8 MJ/ha

(909,000 g $CO_2e\ ha^{-1}\ yr^{-1}$)/(85515.8 MJ/ha) = **10.63 $gCO_2e\ MJ^{-1}$**

This final value is added to the sum of WTT and ethanol combustion to produce the SOC and N_2O corrected GHG intensity for the system above.

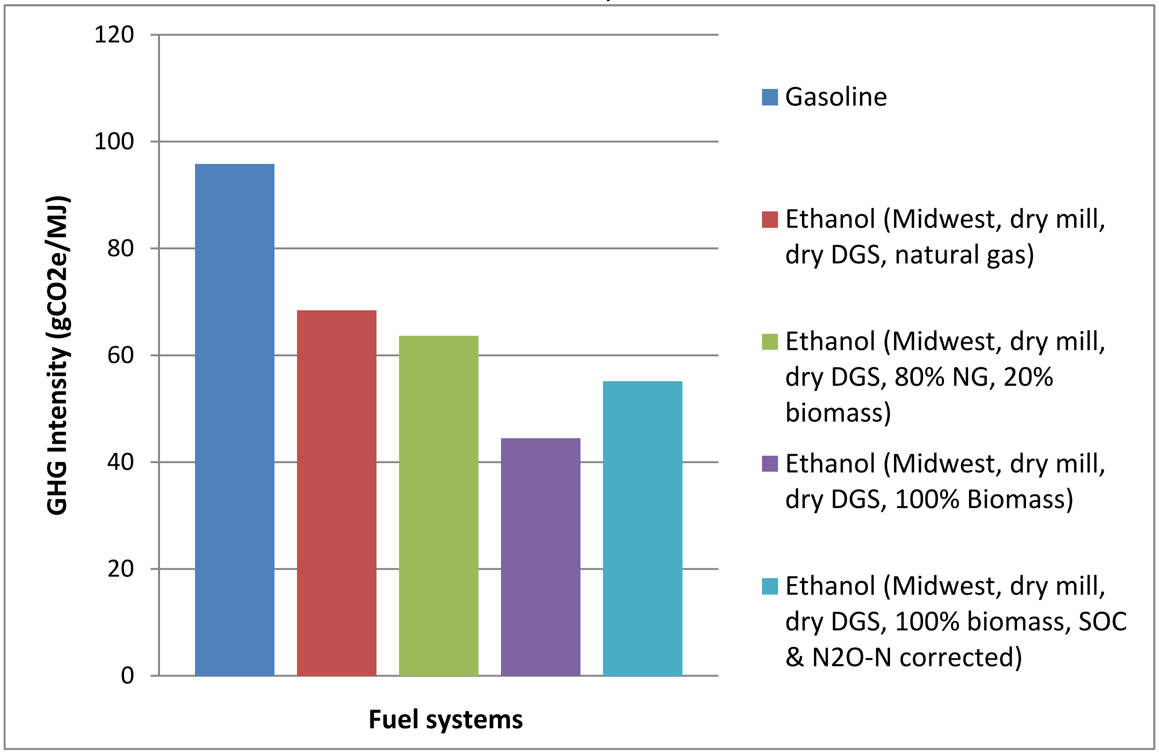
The GHG intensities for gasoline and corn ethanol systems, with and without CHP; and for SOC and N_2O corrected ethanol system with 100% biomass CHP is shown **(Figure 4.8)**. Compared with the three baseline systems, corn ethanol systems powered by 100% biomass are less carbon intensive. The SOC and N_2O corrected corn ethanol system is more GHG intense than the system not accounting for the SOC losses from residue removal.

Table 4.35. CA-GREET model results for gasoline and corn ethanol systems, with and without CHP; and for SOC and N_2O corrected ethanol with 100% biomass CHP.

Fuel Production System	**GHG-Intensity (gCO2e/MJ)**
Gasoline*	95.86
Ethanol*, Midwest, Dry Mill, DGS, Natural Gas	68.40
Ethanol*, Midwest; Dry Mill; Dry DGS; 80% NG; 20% Biomass	63.60
Ethanol†, Midwest; Dry Mill; Dry DGS; 100% Biomass	44.49
Ethanol‡, Midwest; Dry Mill; Dry DGS; 100% Biomass (SOC)	55.13

*Source: CARB look up table, Dec. 14, 2009. All examples do not include indirect land use change emission of 30 gCO2e/MJ. †Modified in the analysis. ‡SOC corrected.

Figure 4.8. GHG intensities for gasoline and corn ethanol systems, with and without CHP; and for SOC and N_2O corrected ethanol system with 100% biomass CHP.



4.3 Appendix I. Application of the DK model to CSP data

The DK model was tested using crop, soil, and weather data from CSP sites 1, 2, and 3 field experiments at Mead in Saunders county from 2001 to 2005. Total C inputs to soil from biomass were calculated based on aboveground biomass residue C determined from field experiments and calculated root biomass C (29% root-to-shoot ratio and 66% of total root fraction in the top 30 cm) (**Table A1**). Direct C input measurements are recognized as more accurate due to rigorous experimental methods, compared to calculated C inputs based on estimated crop yield with uncertain moisture variability. Annual changes in SOC (Mg C ha^{-1} yr^{-1}) between 2001 and 2005 were determined based on two soil measurements in 2001 and 2005 (**Table A2**). These soil measurements are roughly equal to tower eddy covariance flux measurements (**Table A2**). Selected internal parameters for the DK model were adjusted based on site specific temperature measurements from 2001 to 2004 and expert communication (**Table A3**). Soil bulk density and SOC concentration were averaged over the top 30 cm (combining data from 0-15cm and 15-30cm) for 2001 (**Table A4)**. Changes in SOC were estimated using the DK model based on a depth of 30 cm to better approximate total loss of SOC compared to tower eddy covariance flux measurements (**Table A2**).

Based on these parameters, the DK model estimated that no-till residue inputs caused a decrease in SOC (**Table A2 and A4**), which is in agreement with the loss in SOC determined by direct soil measurements and eddy covariance. It is speculated that, over a longer experimental time frame, the rate of C sequestration at those sites is likely to increase, resulting in a smaller SOC loss compared to what is observed at the present stage. This will help narrow the difference between the DK simulated data and those obtained from direct soil measurements and tower eddy covariance flux measurements. Initial settings, internal parameters, and output graph are shown below for the DK model (**Figure A1abc**).

Compared to SOC measurements in the top 30 cm, for the irrigated sites (1 & 2) the DK model predicts less SOC loss (by 0.63 and 0.14% in the first year, calculated respectively), and thus the model is more conservative. But for the rainfed site (3), the model predicts greater SOC loss (by 0.79% in the first year). The model may be behaving in this way because it is insensitive to differences in moisture level—it may assume a lower level of moisture for site 1 & 2 (associated with less SOC oxidation compared to fully irrigated), and it may assume a higher moisture level for site 3 (associated with greater SOC oxidation compared to dry land). For all three sites, the *average* measured SOC loss is 0.57 Mg C ha^{-1} yr^{-1}, or 0.90% loss during the first year, whereas the DK model on average predicts a 0.56 Mg C ha^{-1} yr^{-1}, or 0.91% loss during the first year. Thus on average the model prediction is essentially the measured value, with a negligible difference of 0.01% in the first year across the three sites, and the predicted SOC loss in absolute amount on average is 2% less than measured. But, when the absolute difference between the model prediction and the measurement is considered for the three sites, then the model prediction is off by 0.33 Mg C ha^{-1} yr^{-1}, inaccurate by 0.52%

on average in the first year; or the prediction is off by 42% in *absolute terms for each individual case*. For the purposes of these experiments, a more conservative model prediction is preferable, yet, we would like to minimize the difference between observed and predicted results to the largest degree possible.

The reference temperature of 9^{o}C was calculated as roughly the annual mean temperature in Western Europe where the model derivation originated (Noij *et al*, 1993, Yang & Janssen 2002). This parameter was kept constant for running the DK simulation with both the CSP and CHP data largely because it was used in deriving the values for the initial average rate coefficient (R), and the speed of ageing of residues (S) in the model, and therefore, should not be changed (personal communication, Haishun Yang & Tri Setiyono). Another temperature-related parameter, the Q10 coefficient, was set equal to 2 as this was the value used by most people running the model. For all DK simulations, it was also assumed that on average, there is 0^{o}C difference between soil and air temperature, as supported by the average temperature data in **Table A3** across the three CSP sites.

Table A1. Grain and biomass residue yields (dry matter), and total carbon content for three CSP sites from 2001 to 2004.

Site number	**Crop**	**Year**	**yield (Mg ha^{-1})**	**grain dm (Mg ha^{-1})**	**Harvest Index**	**biomass residue dm (Mg ha^{-1})**	**biomass residue (Mg C ha^{-1})**	**root biomass (Mg C ha^{-1})**	**total C input (Mg C ha^{-1}),** DK inputs
CSP Site 1	maize	2001	13.51	11.42	0.516	10.71	4.86	0.93	5.79
	maize	2002	12.97	10.96	0.528	9.80	4.46	0.85	5.31
	maize	2003	12.12	10.24	0.516	9.61	4.38	0.84	5.22
	maize	2004	12.24	10.34	0.551	8.43	3.82	0.73	4.55
CSP Site 2	maize	2001	13.41	11.33	0.533	9.93	4.46	0.85	5.31
	soybean	2002	3.99	3.47	0.368	5.96	2.68	0.51	3.19
	maize	2003	14	11.83	0.542	10.00	4.54	0.87	5.41
	soybean	2004	3.71	3.23	0.47	3.64	1.63	0.31	1.94
CSP Site 3	maize	2001	8.72	7.37	0.466	8.44	3.77	0.72	4.49
	soybean	2002	3.32	2.89	0.419	4.01	1.8	0.34	2.14
	maize	2003	7.72	6.52	0.498	6.58	2.98	0.57	3.55
	soybean	2004	3.41	2.97	0.491	3.08	1.38	0.26	1.64

Source: Yield data provided by Andrew E Suyker; crop residue biomass C inputs were determined by field experiments (Verma et al. 2004); root biomass C was estimated as 29% of shoot biomass C from Amos and Walters 2006; the top 30 cm soil was estimated to contain 66% of total root fraction assuming a root depth of 120 cm (Jones and Kiniry, 1986, Yang et al., Hybrid-maize, 2006).

Note: Yield moisture content adjusted to 15.5% for maize and 13% for soybean.

Table A2. Soil organic carbon (SOC) dynamics based on direct soil measurement (a), tower eddy covariance (b), and DK model (c) for three CSP sites from 2001-2005.

Site number and cropping system	Measurement method	Depth cm	SOC, 2001 Mg C ha^{-1}	SOC, 2005 Mg C ha^{-1}	Δ SOC 2001-05 Mg C ha^{-1}	Δ SOC 2001-05 Mg C ha^{-1} yr^{-1}	Δ % yr^{-1} in first year
CSP Site 1 Irrigated continuous maize	**(a)**SOC for 400 kg soil	~30	69.38	66.18	-3.2	**-0.8**	**-1.15**
	(b) Tower eddy covariance	–	–	–	–	**-0.7**	**-1.01**
	(c) DK model	30	69.5	68.05	-1.45	**-0.36**	**-0.52**
CSP Site 2 Irrigated maize-soybean	**(a)**SOC for 400 kg soil	~30	57.96	55.72	-2.24	**-0.56**	**-0.97**
	(b) Tower eddy covariance	–	–	–	–	**-1.09**	**-1.88**
	(c) DK model	30	57.9	55.99	-1.91	**-0.48**	**-0.82**
CSP Site 3 Rainfed maize-soybean	**(a)**SOC for 400 kg soil	~30	61.11	59.67	-1.44	**-0.36**	**-0.59**
	(b) Tower eddy covariance	–	–	–	–	**-0.17**	**-0.28**
	(c) DK model	30	61.03	57.66	-3.37	**-0.84**	**-1.38**

Source: Data for (a) and (b) are from Verma et al. 2006; Soil measurements were taken on April 20, 2001 and April 25, 2005; Note: To convert from g C m^{-2} to Mg C ha^{-1}, divide by 100 (divide by 1,000,000 g/Mg and multiply by 10,000 m^2/ha).

Table A3. Average values of air temperature (T_{air}), soil temperature (T_{soil}), and T_{soil} -T_{air} for three CSP sites from 2001 to 2004.

Years	2001-02	2001-02	2001-02	2002-03	2002-03	2002-03	2003-04	2003-04	2003-04	Avg.2001-04
months	May-Sep	Oct-Feb	Mar-Apr	May-Sep	Oct-Feb	Mar-Apr	May-Sep	Oct-Feb	Mar-Apr	
Site 1										
Tair	21.8	4.1	5.9	21.7	0.6	8	20.7	1.1	9.6	10.3
Tsoil	22.3	5	5.1	20.5	0.9	5.6	19.7	3.8	7.5	10.0
Tsoil-Tair	0.5	0.9	-0.8	-1.2	0.3	-2.4	-1	2.7	-2.1	**-0.3**
Site 2										
Tair	22.4	3.9	5.8	21.7	0.5	7.9	20.3	1	9.5	10.3
Tsoil	22.2	4.7	5.3	20.8	3	6.6	19.2	3.5	7.7	10.3
Tsoil-Tair	-0.2	0.8	-0.5	-0.9	2.5	-1.3	-1.1	2.5	-1.8	**0.0**
Site 3										
Tair	22.7	4	5.9	22	0.5	8	20.8	1	9.6	10.5
Tsoil	24	4.6	5.1	22	2.8	6.2	20.9	3.4	7.9	10.8
Tsoil-Tair	1.3	0.6	-0.8	0	2.3	-1.8	0.1	2.4	-1.7	**0.3**

Source: Data from Verma et al. 2005.

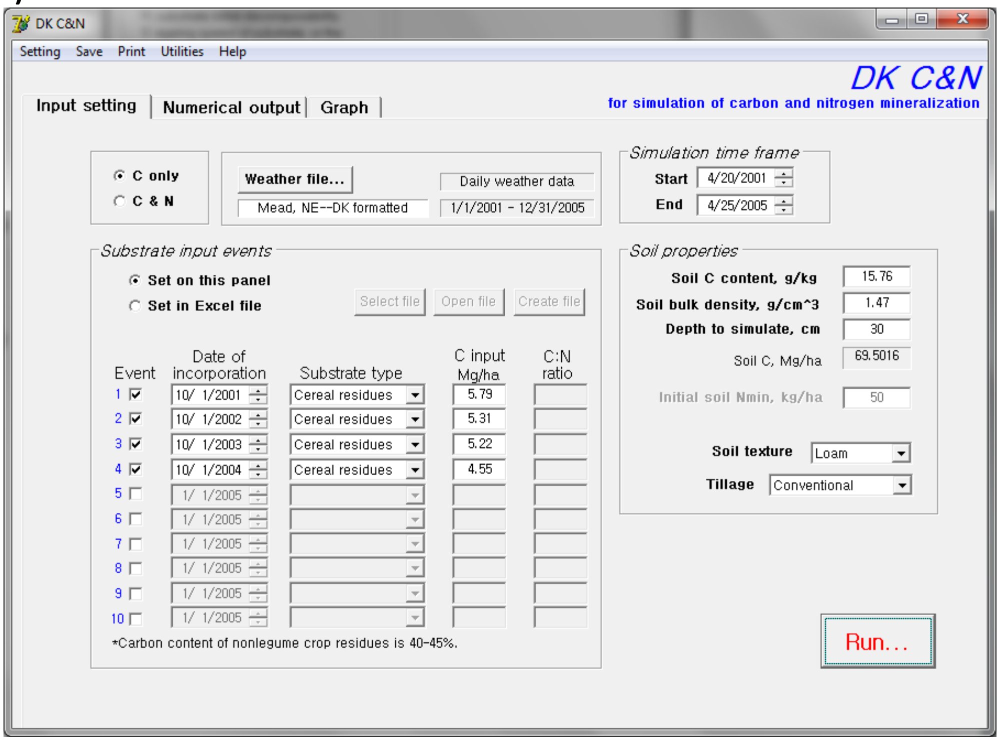
Table A4. Numerical inputs and output from DK simulation model based on measured soil carbon content and bulk density, and direct measurements of C input for three CSP sites from April 20, 2001 to April 25, 2005. Estimates using differences in soil temperature from Table A3 (a), and no difference between air and soil temperature (b) (latter used for county level modeling).

Site number	**Units**	**Site 1-a**	**Site 1-b**	**Site 2-a**	**Site 2-b**	**Site 3-a**	**Site 3-b**
Soil carbon content	$g\ kg^{-1}$	15.76	15.76	13.13	13.13	14.03	14.03
Soil bulk density	$g\ cm^{-3}$	1.47	1.47	1.47	1.47	1.45	1.45
Depth to simulate	cm	30	30	30	30	30	30
Initial SOC, 1/1/2001	$Mg\ C\ ha^{-1}$	69.5	69.5	57.9	57.9	61.03	61.03
Final SOC, 12/30/2004	$Mg\ C\ ha^{-1}$	68.01	68.05	55.99	55.99	57.47	57.66
Δ SOC, 2001-04	$Mg\ C\ ha^{-1}$	-1.49	-1.45	-1.91	-1.91	-3.56	-3.37
Δ SOC, 2001-04	$Mg\ C\ ha^{-1}\ yr^{-1}$	-0.37	-0.36	-0.48	-0.48	-0.89	-0.84

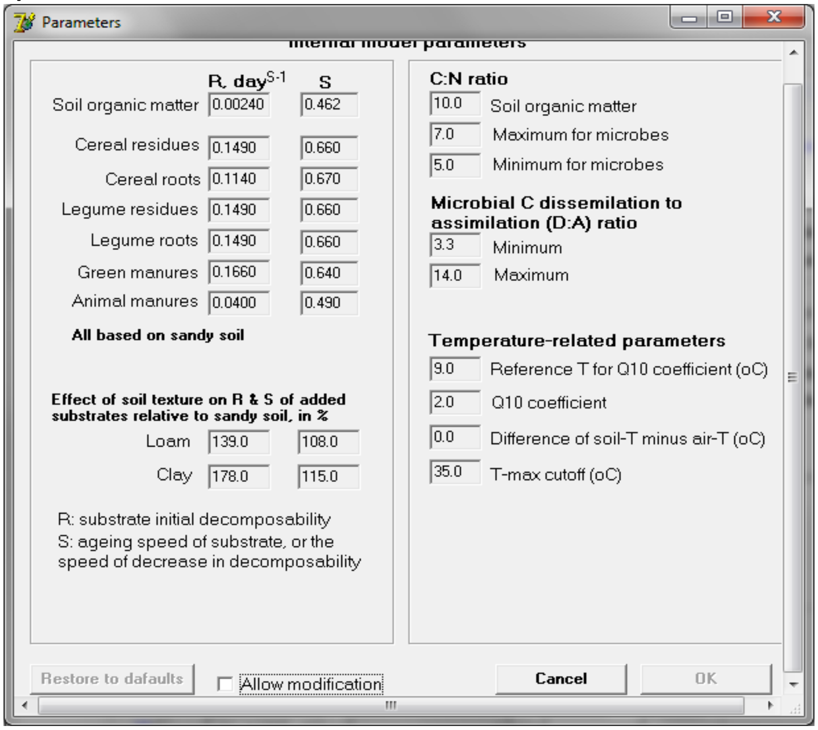
Note: Initial soil measurements were taken on April 20, 2001; soil carbon content and bulk density were averaged over the top 30cm; crop residue C input data were provided by T.Schimelfenig and A.E.Suyker; crop C inputs were determined based on methods by D. Walters (Verma et al. 2004). Data for root C input are based on root biomass C estimated as 29% of shoot biomass C (Amos and Walters, 2006); Biomass inputs were at crop harvest, assumed to be on October 1 during every year.

Figure A1. DK model initial settings **(a)**, internal parameters (**b**), and output graph (**c**) for CSP site 1 simulation.

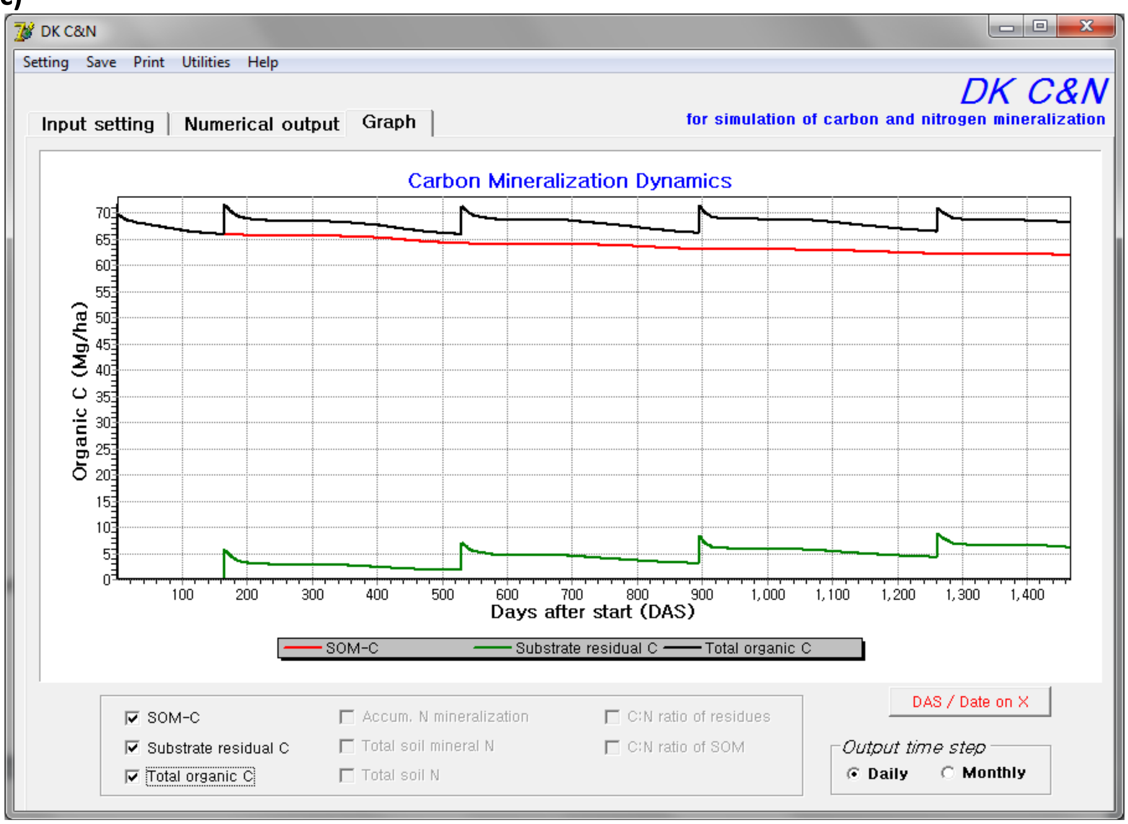
a)



b)


Parameters
Internal model parameters
R, day S-1
S
Soil organic matter
0.00240
0.462
Cereal residues
0.1490
0.660
Cereal roots
0.1140
0.670
Legume residues
0.1490
0.660
Legume roots
0.1490
0.660
Green manures
0.1660
0.640
Animal manures
0.0400
0.490
All based on sandy soil
Effect of soil texture on R & S of added substrates relative to sandy soil, in %
Loam
139.0
108.0
Clay
178.0
115.0
R: substrate initial decomposability
S: ageing speed of substrate, or the speed of decrease in decomposability
C:N ratio
10.0
Soil organic matter
7.0
Maximum for microbes
5.0
Minimum for microbes
Microbial C dissemilation to assimilation (D:A) ratio
3.3
Minimum
14.0
Maximum
Temperature-related parameters
9.0
Reference T for Q10 coefficient (oC)
2.0
Q10 coefficient
0.0
Difference of soil-T minus air-T (oC)
35.0
T-max cutoff (oC)
Restore to dafaults
Allow modification
Cancel
OK

c)


DK C&N
Setting
Save
Print
Utilities
Help
DK C&N
for simulation of carbon and nitrogen mineralization
Input setting
Numerical output
Graph
Carbon Mineralization Dynamics
Organic C (Mg/ha)
Days after start (DAS)
SOM-C
Substrate residual C
Total organic C
SOM-C
Substrate residual C
Total organic C
Accum. N mineralization
Total soil mineral N
Total soil N
C:N ratio of residues
C:N ratio of SOM
DAS / Date on X
Output time step
Daily
Monthly

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5. Potential carbon market opportunities from climate change legislation (Diego Alvarez, Federico Trindade, Richard Perrin)

This research effort explores the potential impact of carbon markets in Nebraska, specifically the impact on the potential for adopting biomass-fired CHP in Nebraska corn ethanol plants. This has required us to monitor and research the progress of climate change legislation, both in the U.S. and abroad. At the end of 2010, it does not appear that federal climate change legislation will be adopted soon, but there are other policies that could affect current adoption incentives, and it is possible that more comprehensive legislation could be passed in the next year or two. In this section we report on the current status of these policies, first the general status of U.S. initiatives, then the Biomass Crop Assistance Program, then the status of international agreements.

5.1 Status of US initiatives to limit GHG emissions

It appears now that a national, economy-wide carbon-pricing policy is unlikely to be enacted before 2013. Nevertheless, as a result of the U.S. Supreme Court decision in Massachusetts v. EPA in 2007, and the administration's subsequent "endangerment finding" that emissions of carbon dioxide and other greenhouse gases endanger public health and welfare, the Environmental Protection Agency (EPA) is now required to regulate GHG emissions under the Clean Air Act. In addition, and acknowledging that national action remains essential for deep emissions cuts, California and two state coalitions – the Western Climate Initiative (WCI) and the Regional Greenhouse Gas Initiative (RGGI)- are implementing their own climate policies.

EPA

EPA has issued regulatory actions and in some cases other statutory authorities to address issues related to climate change. These actions include:

1. Light, Medium and Heavy Duty Vehicle Regulations to Reduce GHGs and Improve Fuel Efficiency

"On April 1, 2010, EPA and NHTSA's final rule set the first-ever harmonized GHG and fuel economy standards for light-duty vehicles for model years 2012 through 2016.

On October 25, 2010, EPA and the NHTSA announced a first-ever Heavy-Duty National Program to reduce greenhouse gas (GHG) emissions and improve fuel efficiency of medium- and heavy-duty vehicles, such as the largest pickup trucks and vans, semi trucks, and all types and sizes of work trucks and buses in between" (http://epa.gov/otaq/climate/regulations.htm).

"Light-duty vehicles are responsible for about 60 percent of U.S. transportation GHG emissions while the heavy-duty sector emits about 20 percent of U.S. transportation GHG emissions" *(ibid).*

"Transportation sources emitted 28 percent of all U.S. GHG emissions in 2007 and have been the fastest-growing source of U.S. GHG emissions since 1990. The mobile sources addressed in this regulatory announcement – light-duty vehicles and heavy-duty vehicles – accounted for 23 percent of all U.S. GHG emissions in 2007" *(ibid).*

2. The Renewable Fuel Standard (RFS)

"This action is intended to ensure that transportation fuel sold in the United States contains a minimum volume of renewable fuel. The new renewable fuel standards (RFS2) implement requirements of the Energy Independence and Security Act of 2007 (EISA) that required the volume of renewable fuel required to be blended into transportation fuel to be 36 billion gallons by 2022" *(ibid).*

"Under the Clean Air Act Section 211(o), as amended by EISA, the EPA is required to set renewable fuel standards each November for the following year based on gasoline and diesel projections from the Energy Information Administration (EIA)". "EPA is also required to set the cellulosic biofuel standard each year" *(ibid).*

Proposed Percentage Standards for 2011 (released on July 2010)

Cellulosic biofuel	0.004-0.015%
Biomass-based diesel	0.68%
Advanced biofuel	0.77%
Renewable fuel	7.95%

3. Greenhouse Gas Reporting Program

"EPA has issued 40 CFR Part 98, which requires reporting of GHG emissions from large sources and suppliers in the United States" *(ibid).*

"Under Part 98, suppliers of fossil fuels or industrial GHGs, manufacturers of vehicles and engines, and facilities that emit 25,000 metric tons or more per year of GHG emissions are required to submit annual reports to EPA. The rule does not require control of greenhouse gases, rather it requires only that sources above certain threshold levels monitor and report emissions" *(ibid).*

Entities covered include:

—Electricity generating facilities that are subject to the Acid Rain Program (ARP) or otherwise report CO_2 mass emissions year-round through 40 CFR part 75;
—Lime manufacturing;
—Petrochemical production;
—Petroleum refineries;
—Manure management systems that emit CH_4 and N20 (combined) in amounts equivalent to 25,000 metric tons CO_2e or more per year;
—Facilities that produce ferroalloy, glass, hydrogen, iron and steel, lead, pulp and paper, and zinc and that emit 25,000 metric tons CO_2e or more per year in any calendar year starting in 2010;

and others.

“This new program will cover approximately 85 percent of the nation’s GHG emissions and apply to roughly 10,000 facilities” *(ibid).*

“It supplements and complements, rather than duplicates, existing U.S. government programs (e.g., climate policy and research programs). For example, EPA anticipates that facility-level GHG emissions data will lead to improvements in the quality of the Inventory of U.S. Greenhouse Gas Emissions and Sinks (Inventory), which EPA prepares annually, with input from several other agencies, and submits to the Secretariat of the United Nations Framework Convention on Climate Change (UNFCCC)” *(ibid).*

4. Prevention of Significant Deterioration and Title V Greenhouse Gas Tailoring Rule

“This rule sets thresholds for GHG emissions that define when permits under the New Source Review Prevention of Significant Deterioration (PSD) and title V Operating Permit programs are required for new and existing industrial facilities” *(ibid).*

“This final rule “tailors” the requirements of these CAA permitting programs to limit which facilities will be required to obtain PSD and title V permits. Facilities responsible for nearly 70 percent of the national GHG emissions from stationary sources will be subject to permitting requirements under this rule. This includes the nation’s largest GHG emitters— power plants, refineries, and cement production facilities. Emissions from small farms, restaurants, and all but the very largest commercial facilities will not be covered” *(ibid).*

“Under these rules, beginning in 2011, projects to build a new power plant or factory or upgrade an existing facility that will increase GHG emissions substantially (more than 25,000 tons of carbon-dioxide per year), will require an air permit and be required to adopt the "best available control technology" for greenhouse gas emissions. To develop a performance standard, EPA would identify the technologies that pollute the least for a given industry sector and require all companies in that sector to pollute no more than if they used those best demonstrated technologies” *(ibid).*

California

In 2006, California's Legislature passed and Governor Schwarzenegger signed AB 32, the Global Warming Solutions Act of 2006, which set the 2020 greenhouse gas emissions reduction goal into law (AB 32 requires that by 2020 the state's greenhouse gas emissions be reduced to 1990 levels, a roughly 25 percent reduction compared to business as usual estimates).

The reduction measures to meet the 2020 target are to be adopted by the start of 2011.

"The Assembly Bill 32 Scoping Plan contains the main strategies California will use to reduce the greenhouse gases (GHG) that cause climate change. The scoping plan has a range of GHG reduction actions which include direct regulations, alternative compliance mechanisms, monetary and non-monetary incentives, voluntary actions, market-based mechanisms such as a cap-and-trade system, and an AB 32 program implementation regulation to fund the program". (http://www.arb.ca.gov/cc/scopingplan/scopingplan.htm)

"The AB 32 Scoping Plan identifies a cap-and-trade program as one of the strategies California will employ to reduce the greenhouse gas (GHG) emissions that cause climate change" *(ibid).*

"Consistent with AB 32, ARB must adopt the cap-and-trade regulation by January 1, 2011, and the program itself must begin in 2012. This program would cover 85 percent of the State's GHG emissions" *(ibid)*.

The "Preliminary Draft of Regulation for a California Cap-and-Trade Program" proposes a staggered approach that was outlined in the Scoping Plan, under which entities in the following sectors would be covered in the program according to the following timelines:

"Starting in the first compliance period (2012):

—Lime manufacturing;

—Electricity generation, including imports;

—Large industrial sources and processes at or above 25,000 MTCO2e.

Starting in the second compliance period (2015):

—Industrial fuel combustion at facilities with emissions below 25,000 MTCO2e, and all commercial and residential fuel combustion of natural gas and propane;

—Transportation fuels" *(ibid)*.

Without a staggered approach, all sectors identified above would be subject to the cap-and-trade program on January 1, 2012.

"In addition, California is working closely with six other western states and four Canadian provinces through the Western Climate Initiative (WCI) to design a regional cap-and-trade program that can deliver GHG emission reductions within the region at costs lower than could be realized through a California-only program. To that end, the ARB rule development schedule is being coordinated with the WCI timeline for development of a regional cap-and-trade program" *(ibid)*.

Other measures, such as Clean Car Standards, the Low Carbon Fuel Standard Program, the Landfill Methane Control Measure and the HFC Emission Reduction Measures for Mobile Air Conditioning are also important parts of the scoping plan.

Western Climate Initiative

The Western Climate Initiative (WCI), formed by seven U.S. states (Arizona, California, Montana, New Mexico, Oregon, Utah and Washington) and four Canadian provinces (British Columbia, Manitoba, Ontario and Quebec) which together represents 13 percent of U.S. and 50 percent of Canadian greenhouse gas emissions, has compiled a detailed plan for implementing a market-based system to reduce GHG emissions in their region to 15 percent below 2005 levels by 2020.

The central component of the WCI strategy is a regional cap-and-trade program. "The Design for the WCI Regional Program, released on July 27, 2010, provides a roadmap to inform the WCI Partner jurisdictions as they implement the cap-and-trade program in their jurisdictions. Those expected to implement the program when it begins in January 2012 comprise approximately two-thirds of total emissions in the WCI jurisdictions. When fully implemented in 2015, this comprehensive program will cover nearly 90 percent of the GHG emissions in WCI states and provinces" (http://www.westernclimateinitiative.org/designing-the-program)

"The WCI cap-and-trade program will cover emissions of seven greenhouse gases (carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, sulfur hexafluoride, and nitrogen trifluoride) from the following types of emission sources (if they emit at least 25,000 metric tons of carbon dioxide equivalents (CO2e) annually):
—Lime manufacturing;
—Electricity generation, including electricity imported into the WCI region;
—Industrial fuel combustion;
—Industrial processes;
—Transportation fuel use;
—Residential and commercial fuel use".
(http://www.westernclimateinitiative.org/the-wci-cap-and-trade-program)

"The first phase of the cap-and-trade program begins on January 1, 2012, covering emissions from electricity, electricity imports, industrial combustion at large sources, and industrial process emissions for which adequate measurement methods exist. The second phase begins in 2015, when the program expands to include transportation fuels and residential, commercial and industrial fuels not otherwise covered in the first phase" *(ibid).*

In addition, the WCI is exploring ways to join with other regional GHG markets in the future through the three regions initiative. There's also cooperation between RGGI and WCI so that in the future they could be linked up, possibly with Europe's system, and possibly with offset projects in, say, China and India.

RGGI

"The RRGI is the first mandatory, market-based effort in the United States to reduce greenhouse gas emissions. Ten Northeastern and Mid-Atlantic states (Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New York, New Jersey, Rhode Island and Vermont) have capped and will reduce CO2 emissions from the power sector 10% by 2018" (http://www.rggi.org/home)

The program began capping emissions at current levels in 2009.

"The applicability criteria require fossil fuel fired electric generating units serving a generator of 25 MW or larger to comply with the CO2 Budget Trading Program" (http://www.rggi.org/docs/program_summary_10_07.pdf).

"Regionally, units of this size are responsible for approximately 95% of CO2 emissions from the electric generation sector" *(ibid).*

"CO2 emissions attributable to the combustion of eligible biomass at a CO2 budget unit can be deducted from that unit's CO2 compliance obligation. Eligible biomass includes sustainably harvested woody and herbaceous fuel sources that are available on a renewable or recurring basis (excluding oldgrowth timber), including dedicated energy crops and trees, agricultural food and feed crop residues, aquatic plants, unadulterated wood and wood residues, animal wastes, other clean organic wastes not mixed with other solid wastes, biogas, and other neat liquid biofuels derived from such fuel sources. Determinations as to what constitutes sustainably harvested biomass shall be made by the applicable regulatory agencies in each participating state" *(ibid).*

"The RGGI MOU calls for signatory states to stabilize power sector CO2 emissions over the first six years of program implementation (2009-2014) at a level roughly equal to current (by year 2007) emissions (188 million short tons of CO2 per year), before initiating an emissions decline of 2.5% per year for the four years 2015 through 2018. The first three year compliance period would begin January 1, 2009" *(ibid).*

The Accord

The Midwestern GHG Reduction Accord (the Accord) establishes a cap-and-trade program to reduce anthropogenic emissions of greenhouse gases from the covered sources (see below) 20% below 2005 levels by December 31, 2020 and 80% below 2005 levels by December 31, 2050.

"The first compliance period for the cap-and-trade program will begin January 1 of the first calendar year that is at least 12 months after the adoption of the model rule and execution of an implementing memorandum of understanding by the participating jurisdictions. If an economy-wide federal [Canada/U.S.] cap-and-trade system is adopted, this rule will be amended to promote a smooth transition into such program". (http://www.midwesternaccord.org/Final_Model_Rule.pdf)

Members: Iowa, Illinois, Kansas, Manitoba, Michigan, Minnesota, Wisconsin.

Observers: Indiana Ohio Ontario South Dakota.

Covered Sources: Any source that emits over 25,000 metric tons CO2e annually in combined emissions, based on a three year rolling average and excluding emissions from combustion of eligible biomass, from one or more of the categories listed in this paragraph.

(i) General stationary fuel combustion at industrial sources

(ii) Process or other emissions, excluding biogenic emissions of carbon dioxide from fermentation processes, from industrial sources in the following categories:

(A) Adipic acid manufacturing
(B) Aluminum manufacturing
(C) Ammonia manufacturing
(D) Carbon dioxide transfer recipients
(E) Cement manufacturing
(F) Coal mine fugitive emissions (active and abandoned)
(G) Coal storage
(H) Cogeneration
(I) Electronics Manufacturing
(J) Ferroalloy production
(K) Glass Production and other uses of carbonates
(L) HCFC-22 production
(M) Hydrogen production
(N) Industrial wastewater
(O) Iron and steel manufacturing
(P) Lead production
(Q) Lime manufacturing
(R) Magnesium production
(S) Natural gas transmission and distribution systems
(T) Nitric acid manufacturing

(U) Nonroad equipment at facilities
(V) Oil and gas production & gas processing
(W) Petrochemical production
(X) Petroleum refineries
(Y) Phosphoric acid production
(Z) Pulp and paper manufacturing
(AA) Refinery fuel gas
(BB) SF6 from electrical equipment
(CC) Soda ash manufacturing
(DD) Zinc production

-Any first jurisdictional deliverer of electricity, including generators, retail providers, and marketers, that provide electricity into the region, the production of which generates greater than 25,000 metric tons CO_2e annually, based on a three year rolling average and excluding emissions from combustion of eligible biomass.

- Any fuel supplier within the region that distributes liquid transportation fuel, petroleum coke, natural gas, propane, or heating fuel in quantities that when combusted would emit over 25,000 metric tons CO_2e annually, based on a three year rolling average and excluding emissions from combustion of eligible biomass.

5.2 A summary of relevant 2008 Farm Bill provisions

The following excerpts are provided from the following source: (http://www.usda.gov/documents/FB08_Pub_Mtg_Renew_Energy_Factsheet.pdf)

"Section 9004: Repowering Assistance Program—Section 9004 authorizes payments to encourage biorefineries in existence when the Farm Bill was passed to replace fossil fuels used for operational power with biomass power. Payments would be made for installation of new biomass systems.

Section 9005: Bioenergy Program for Advanced Biofuels—Section 9005 provides for payments to be made to eligible agricultural producers to support and ensure an expanding production of “advanced biofuels.” Advanced biofuels under the bill are essentially those fuels derived from renewable biomass other than corn-kernel starch and include, among others, ethanol from waste materials. Further, advanced biofuels must have life-cycle greenhouse gas (GHG) emissions at least 50 percent less than baseline (2005) life-cycle GHG emissions for gasoline or diesel as specified by the Energy Independence & Security Act of 2007.

Section 9007: Rural Energy for America Program—Section 9007 is designed to promote energy efficiency and renewable energy development for agricultural producers and rural small businesses and provides grants and loan guarantees for energy audits, feasibility studies and project development of renewable energy systems/energy efficiency improvements. Grants in certain instances, however, may not exceed 25 percent of cost. Loan guarantees are capped at $25 million per loan, and any combination of grant and loan guarantees may not exceed 75 percent of cost.

Section 9008: Biomass Research and Development Initiative—Section 9008 provides competitive grants, contracts and financial assistance to eligible entities to carry out research on and development and demonstration of biofuels and biobased products, and the methods, practices and technologies for their production.

Section 9011: Biomass Crop Assistance—Section 9011 provides support to establish and produce crops for conversion to bioenergy, and to help agricultural and forest landowners with the collection, harvest, storage and transportation of eligible material for use in a biomass conversion facility.

Section 9012: Forest Biomass for Energy—Section 9012 appropriates $15 million annually for fiscal year 2009-'12 for the Forest Service to administer a competitive and comprehensive research and development program to use forest biomass for energy. The Forest Service, other federal agencies, state and local governments, Indian tribes, land-grant colleges and universities, and private entities are eligible to compete for such program funds. The priority research projects include: developing technology and techniques to use low-value forest biomass for energy production; developing processes to integrate energy production from forest biomass into biorefineries; developing new transportation fuels from forest biomass; and improving growth and yield of trees intended for renewable energy."

5.3 Federal Support for Biomass Crops: the Biomass Crop Assistance Program (BCAP)

The Biomass Crop Assistance Program (BCAP) was enacted in the 2008 Farm Bill to support the production of advanced biofuels and renewable energy. The legislation provides two components of support for biomass used for conversion to heat, power, advanced biofuels or bioproducts:

1. *CHST Matching Payments* - Matching of market prices paid for biomass by qualified biomass conversion facilities (BCFs) for the collection, harvest, storage and transportation (CHST) of eligible biomass .
2. *Crop Establishment and Annual Payments* - Payments made to producers for energy crops to be delivered to BCFs, consisting of reimbursement for some establishment costs and annual contract payments for land use for up to 5 years (15 years for woody crops).

Under initially proposed rules for the CHST component, during 2009 and 2010 USDA spent about $250 million, far more than the $70 million Congress projected for the program through 2012. Less than $1 million of this went to agricultural crops. Virtually all was paid to sawmills and lumber wholesalers that were already collecting woody resources and wastes. This was authorized by the legislation, but not its primary intent. USDA then suspended new CHST enrollment in February, 2010, and published a revised, final rule on October 27, 2010. As of mid-November, 2010, the Farm Service Agency (FSA), the agency administering the program, had not yet specified detailed program requirements and application procedures.

The final rule provides guidelines intended to limit the eligibility of woody materials to those collected from the land for this purpose, rather than byproducts from wood processing. But no guidelines are offered for allocating funds between woody resources and wastes versus agricultural crops, and it is possible that the bulk of funds could continue to be allocated to woody biomass.

Both BCAP components require agreements to deliver biomass to qualified BCFs, a list of which will be available at http://www.fsa.usda.gov/bcap

Perennial Crop Establishment and Annual Payments

Producers can be reimbursed for up to 75% of establishment costs for perennial crops, plus annual payments for up to five years (15 years for woody biomass crops). In addition to these payments, upon delivery of the biomass, producers may be eligible for CHST matching payments. Prior agreements and contracts are required to be eligible for these payments.

"BCAP Project Areas". Eligibility for payments is initiated when a "sponsor" (a group of crop producers or a BCF) applies through the FSA for selection as a "BCAP project area". The application specifies the geographical area, the crops, the method for determining payment amounts and also certifies the commitment of the BCF. Only private lands within project areas are eligible, and general conservation plans must be included in the proposal. Proposals are then evaluated by USDA for selection.

"BCAP contracts". Producers within a project area enroll contract acreage for the production of eligible crops, for up to five years (15 for woody biomass). The enrollment contract is to include a conservation plan. Eligible crops include switchgrass, miscanthus, poplar, jatropha, algae and energy cane.

Procedures for setting rates for establishment costs and annual payments are similar to those for land enrolled in the Conservation Reserve Program (CRP). Rate information is to be posted at county FSA offices. Annual payments are reduced by 10% if the biomass is sold for advanced biofuels and by 25% if sold for heat, power or biobased products (i.e., biomass for cellulosic biofuels receives a preference).

CHST Matching Payments

The assistance offered is a payment of up to $45 per dry ton to producers for eligible biomass, matching dollar-for-dollar the payment made by the biomass conversion facility (BCF). Payments are made to the producer who harvests and transports eligible material. These payments are limited by the legislation to a maximum of two years per producer. To be eligible, the producer must receive approval in advance through an FSA county office. Each BCF must enter into a separate agreement through FSA to become qualified.

Biomass must be collected and harvested under approved plans for stewardship and conservation practices. Materials eligible include many crop residues as well as specific dedicated biomass crops and woody materials. Eligibility of materials is subject to other restrictions. Guidelines for plans and application processes were not announced by mid-November, 2010.

5.4 International Negotiations on Climate Change:

The **Kyoto Protocol** is the most important global agreement about climate change created so far. It was signed in 1997 and was ratified by most of the industrialized and developing countries. It is part of the negotiations held within the **UN Framework Convention on Climate Change (UNFCCC)** started in 1992, whose goal was to limit **greenhouse gases (GHG)** emissions. The UNFCCC set no mandatory limits on greenhouse gas emissions and contained no enforcement mechanisms, but it created a framework for further negotiations that would lead to mandatory emission limits; the **Kyoto Protocol** is one of these.

Recognizing the fact that the industrialized economies were the most important contributors to the high level concentration of GHG accumulated in the atmosphere today, most of the burden of the Kyoto Protocol falls over them. This is why industrialized countries (called Annex I parties) agreed to legally binding reductions in greenhouse gas emissions. Developing countries (Non-Annex I parties) do not have quantitative emission reduction commitments, but they are committed to mitigation actions. The goal of the protocol is to reduce GHG emissions by 5.2% in average with respect to 1990 levels by the year 2012. Up to October 2010, 191 countries have signed and ratified the treaty; United States (36.1% of GHG emissions in 1990) has not ratified it.

In December to 2007 the UNFCCC met in Bali, Indonesia, with the main goal of establishing a framework of negotiation for a new long-term climate change regime to be signed two years later. The meeting culminated in the adoption of the **Bali Road Map**, where governments of developed and developing countries agreed to reach agreements and to joint efforts to combat climate change. The Bali Road Map included the **Bali Action Plan (BAP)** which provided a roadmap toward a new international climate change agreement to be signed in 2009. The Bali Action Plan was centered on four main pillars: **mitigation** of GHG emissions, **adaptation** to help developing countries to adapt to impacts of climate change, **technology** that reinforces adaptation through the supply of technology, and **financing** to generate financial flows to help developing countries to reach the goals without resigning to economic growth and poverty eradication. The idea of developing countries taking actions to mitigate emissions is very important given their rapidly increasing share of global GHG emissions.

Another key outcome of the meeting in Bali was the importance that was given to deforestation as a key driver of climate change. Land use change, mainly in the form of deforestation, contributes about 20% of global GHG emissions. A proposal was made on the need to take further meaningful actions to **Reduce Emissions from Deforestation and forest Degradation (REDD)** and a conference was set to be held in 2009 as a deadline to reach an agreement. REDD calls upon governments, NGOs and the private sector from developed economies to use monetary incentives in order to encourage developing countries to mitigate their GHG emissions due to deforestation and forest degradation.

Another important point to highlight is that Bali meant the return of the United States to the negotiating process within the UNFCCC framework for the first time after the withdrawal from the Kyoto Protocol back in March of 2001. The last global UNFCCC meeting was held in Copenhagen in 2009. Given that the Kyoto Protocol expires in 2012, it was expected that a new mandatory agreement would replace and extend it. However, despite the high expectations and much political pressure, it became clear before the conference that reaching a comprehensive post-2012 binding agreement for long-term action would not be possible.

As a result of the meeting a parallel political accord was reached, which is external to the UNFCCC negotiations. The "**Copenhagen Accord**" was promoted by 25 countries, including the United States and China who helped to write the draft. In the Accord, countries committed to keep global temperature rise below 2°C through deep cuts in GHG emissions, achieving the peak of global emissions as soon as possible, while noting that emissions in developing countries will take longer to reach their peak. Developed countries (Annex I) commit to implement individually or jointly quantified economy-wide emissions targets and developing countries (Non-Annex I) will implement nationally appropriate mitigation actions. In total, nations that represent 80% of the global GHG emissions committed to submit reduction goals (Annex I) and mitigation actions (non-Annex I) for the period up to 2020. So far 138 countries have already submitted their targets; this represents more than 80% of the global emissions. Within these countries are Brazil with a reduction of about 37%, China between 40% and 45%, European Union between 20% and 30%, Indian between 20% and 25%, Japan 25% and the United States 17%.

The agreement also pledges US$ 30 billion to developing countries over the period 2010-2012, with the commitment to reach US$ 100 billion per year from 2020 onward, to help them to mitigate GHG emissions. The funding will be balanced between adaptation and mitigation; and for adaptation, it will be prioritized for the most vulnerable countries.

The Accord also calls for the immediate establishment of **REDD+** (which also includes enhancing existing forests or creating new ones to increase forest cover) to enable the mobilization of financial resources from developed countries. Pledges of US$3.5 billion were made during the Copenhagen meeting, and have been extended to US$ 4.5 billion in posterior meetings during 2010.

During 2010 there were four preparatory rounds of negotiations for the meeting to be held in **Cancún**, México, from November 29th to December 10th of 2010. The goal of the Cancún meeting is to sign a mandatory agreement to replace Kyoto Protocol, but the expectations are very low since the different points of view that support the biggest economies, notably US, UE and China.

6. Relationships among energy prices relevant to the feasibility of CHP adoption - a vector error correction model time series approach. (Kepifri Lakoh and Lilyan Fulginiti)

Introduction

The economic feasibility of adoption of biomass fired CHP in Nebraska corn ethanol plants depends in part on the price levels of energy inputs. Ethanol plants use natural gas and electricity, and the higher are these energy prices the more attractive is CHP. But production and delivery of biomass uses diesel fuel, and the higher is that price, the higher must be the price of biomass, thus making CHP less attractive. At prices prevailing in 2009, CHP is not an economical technology, but if diesel, natural gas and electricity prices all rise at the same rate, CHP will ultimately become profitable because diesel is a smaller component of cost than natural gas or electricity. This raises the issue of whether these prices do tend to move together, and if so, how long it takes for them to equilibrate. This is the motivation for the study reported here.

This study hypothesizes that: An increase in crude oil prices would increase energy prices which in turn would increase the cost of agricultural inputs generally. The expected rippling effect of this increase would be an increase in demand and supply of cellulose to levels that would eventually create a feasible market for the product.

6.1 Objectives

- Use time series analysis to determine the directional effect of an increase in crude oil prices on Energy-related farm input (Diesel, Natural Gas and Electricity) prices.
- Forecast farm input energy price trends for the next five years.

6.2 Methodology

To obtain an initial impression of the dataset, a preliminary, univariate, descriptive statistics analysis was carried out. The respective variables were tested for stationarity using the ARIMA framework. Two main complementing time series analysis methodologies were applied in this study. In the short run, we estimated a Structural Vector Autoregressive (SVAR) model. However when cointegaration tests were carried out on the system, there was strong evidence of the variables cointegrating. In correcting for this anomaly, vector error correction models (VECM) were introduced and estimated. Within the framework of the VECM, the series of interest were then forecasted to obtain expected prices over a five year period.

6.3 Data

The main data sources for this study were the US Department of Energy and the Nebraska department Energy websites. The four variables of interest (Crude Oil, Diesel, Natural Gas and electricity)[4] were measured in Nominal Dollars per Million BTU. This is to enhance effective comparison of all the variables with the standard energy unit. The series used was annual over the period 1970 to 2010. Table 1 and figure 1 give a brief description of the data set.

The correlation matrix of the four variables as shown in Table 2, reports a very high correlation amongst the four variables. It shows a correlation of 96% between crude oil and diesel prices. A similar average (96%) was also obtained for the correlation between natural gas and diesel as is also the case for natural gas and electricity. Those for natural gas and crude oil prices were 87%, electricity and diesel were 91% while that for electivity and crude oil was 82%.

6.4 Data Analysis

The Augmented Dickey-Fuller (ADF) test was used to determine the presence or absence of unit-roots and the appropriate order of integration of each univariate series should they prove nonstationary. The results of the tests are presented in Table 3. From the ADF results, all four variables were nonstationary and attempts to difference the data led to the conclusion that lcrude, ldiesel and lngas were stationary after first differencing while lelect was stable after the second difference.

The Johansen Cointegration (JC) test was then carried out to determine whether the variables were cointegrated. The JC method is designed to determine the cointegrating rank, r, or the degree of cointegration using the likelihood ratio (LR) test

[4] The following conversions were used: Electricity: 1kilowatthour = 3412 BTU, crude oil: 1 barrel = 42 U.S gallons = 5800000 BTU and diesel fuel: 1 gallon = 138690 BTU.

(Holden and Perman, 1994; Vickner and Davies, 2000). From this test, a rank of zero would signify the absence of cointegration amongst the variables. However any rank otherwise proves or confirms the presence of some form of cointegration amongst the variables. The results are presented in Table 3. The results revealed that the rank cannot be zero because the critical value for rank=0 was less than the trace value. This means that there is some degree of cointegration amongst the variables. The most suitable rank was 3.

From the results obtained from the ADF and JC tests, a vector error correction (VEC) model is more appropriate than a vector autoregression (VAR) model to characterize the multivariate relationships among the four series (Engle and Granger, 1987; Enders, 1995).

6.5 The VEC Model

A vector error correction model is a restricted form of a VAR model. The VECM restricts long-run behavior of the dependent variables so that they converge to their long run equilibrium and allow short run dynamics. It is particularly useful for forecasting purposes, more so when some degree of cointegration is suspected in the system. The extended form of the General VEC model can be represented as shown below.

$$\begin{bmatrix} \Delta C_t \\ \Delta D_t \\ \Delta N_t \\ \Delta E_t \end{bmatrix} = \begin{bmatrix} \pi_{11} & \pi_{12} & \pi_{13} & \pi_{14} \\ \pi_{21} & \pi_{22} & \pi_{23} & \pi_{24} \\ \pi_{31} & \pi_{32} & \pi_{33} & \pi_{34} \\ \pi_{41} & \pi_{42} & \pi_{43} & \pi_{44} \end{bmatrix} \begin{bmatrix} C_{t-1} \\ D_{t-1} \\ N_{t-1} \\ E_{t-1} \end{bmatrix} + \begin{bmatrix} e_1 \\ e_2 \\ e_3 \\ e_4 \end{bmatrix}$$

In the above system of equations, the Pie weights represent the error correction term. The$\boldsymbol{\pi}_{.1}$ parameters represent the speed of adjustment parameters while the rest of the $\boldsymbol{\pi}$ contains the speed of adjustment parameters and the cointegrating equations. More explicitly, the cointegrating term would be ($C_{t-1} - \pi_{.2}D_{t-1} - \pi_{.3} N_{t-1} - \pi_{.4}E_{t-1}$). This is the error correction term since the deviation from long run equilibrium is corrected gradually through short-run adjustments. In this framework C_t, D_t, N_t and E_t are treated as being endogenous.

6.6 Granger Causality

To help in determining which of the variables considered were endogenous and which were exogenous to the system of equations, granger causality techniques were employed. Granger causality is a method for determining whether one series is useful in forecasting another series.

Ten plausible models were tested and from the results obtained, five were significant at a 5% level of significance. The Wald test statistics results are as shown in table 4. Robustness of a model was being determined by two information criteria, the AIC, SBC Information Criteria. The most robust model was model ten which infers that lcrude granger causes ldiesel, lngas and lelect. The rest of the analysis uses this multivariate structure as the most appropriate model.

6.7 Forecasts

This section is aimed at exploring the potential effects of a ten percentage change in crude oil prices on other farm energy prices (diesel, natural gas and electricity). This would help policy makers in determining the extents to which crude oil price fluctuations affect farm energy prices.

In carrying out this exercise, a very basic methodology is employed and some underlying assumptions made. The shock or percentage change is applied to the independent variable at time t. With this introduction, the whole vector error correction system is re-estimated and forecasts obtained for time t+i (for i = 1 to 5).

6.8 Summary of Results

Estimates of the VECM model are as shown in table 5. The signs and proportion of magnitudes are very much in line with our expectations from the series correlations reported in table 2. The cointegrating relationships between the three dependent variables (lelect, ldiesel and lngas) and crude oil prices were positively related with varying magnitudes. This infers that if crude oil prices continue increasing, natural gas, diesel and electricity prices would also converge to an increasing trend in the long-run. Table 6 shows the results from the corresponding alphas (the speed of adjustment towards Equilibrium) and betas (the structural long run relationships between the variables). These would be useful when the forecast results are discussed below.

The results from the five years forecast reveal all three prices would trend upwards over the five years period. For diesel prices, they are further expected to fall in 2011 relative to 2010 levels and then recover with marked increases in subsequent years. Natural Gas and electricity are forecasted to increase annually by an average of about 1 to 2 % annually.

When the price of crude oil in period t (2010) was assumed to have increased by 10% of its preceding year’s (2009) price, a similar upward trend in the other energy prices was observed. In terms of direction, all three variables moved in the directions as described above. However it must be noted that the actual price increase from period t-1 to period t was greater than 10%. This is clearly seen in the path graphs shown in the appendix section. The aggregate effect of a 10% increase on crude oil prices is represented as the vertical distance between the original series forecast and the 10% series forecast. These are illustrated in the graphs below. It is clearly shown that all three responding prices would increase at an increasing rate over the next five years. All three variables express no signs of convergence within the forecast period. However as shown by the speed of convergence parameters and in figure 6, diesel prices would be the first to converge followed by natural gas and then electricity.

6.9 Concluding Remarks

The Principal objectives of this study were to use time series techniques to determine the directional effect of an increase in crude oil prices on energy-related farm input (Diesel, Natural Gas and Electricity) prices and to forecast farm input energy price trends for the next five years. Using the JC test, there was evidence of cointegration amongst the variables which justifies the use of VECM for the rest of the analysis. This meant that even though they respectively move separately in the short run, they do move in the same direction in the long-run. Causality was being determined using the granger-causality technique. The most robust of the models revealed that natural gas, electricity and diesel prices were all granger caused by crude oil prices. (Robustness was being determined by the AIC and SBC criteria).

The estimates of the VECM revealed that if crude oil prices continue increasing, natural gas, diesel and electricity prices would also converge to an increasing trend in the long-run. The reverse is also true for a decrease in crude oil prices. Forecast results revealed that all three prices would be trending upwards over the next five years. Diesel prices are however expected to be the most volatile of the three. There should be a 5% decline in 2011 before experiencing significant ascensions over the next four years. Natural gas and electricity prices are expected to increase annually on steady rate averaging between 1.5% to 2.5% annual increases.

With a 10% increase in crude oil prices, the model revealed that natural gas, electricity and diesel prices would also increase steadily at annual rates averaging 0.5 to 2.5 %, with the greatest increase being seen in diesel prices.

6.10 Next Steps

One major shortcoming of this analysis is its lack of the use of a market structure to set the basis for describing these trends. It lacks the ability to describe the substitutability or complementarity properties that may be imbedded in these relationships. One Major next step is to include a multi-market economic component to the analysis to improve on the structure and accuracy of the estimate and forecasts.

Other studies have used other robust models in performing forecasts. A suitable next step would be to compare these models to the VECM and test perform test to see which of these models best forecast the data.

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7. Carbon release estimates from land use change – a review (L. Fulginiti, A. Kibonge)

The following studies were reviewed with the objective of identifying emission weights used in calculation of indirect land-use changes due to increases in the price of corn derived from its use as a biofuel source: (A) the Searchinger, et al. 2008 paper, (B) the California Air Resources Board (CARB) Low Carbon Fuel Standard Program report, (C) the EPA Renewable Fuel Standard (RF2) report, (D) the Hertel et al., Bioscience 2010 paper, (E) the Melillo et al. Science, 2009 paper, (F) the Hiederer et al. Science 2009 paper, (G) the Weitzke et al. 2010 paper, and (H) Edwards et al. 2010 paper.

All except the last two follow these steps:

1) Estimate extra area of land.
2) Determine which land in which countries is converted.
3) Estimate the amount of carbon releases from conversion in each ecosystem, then apply it to each country.

Weitzke et al. and Edwards et al. are comparisons of alternative models used to calculate ILUC effects and we present a summary of their conclusions.

7.1 The Searchinger, et al, Science 2008

First Step: Calculate extra area of land. Model used: FAPRI, econometric. Shock: increase in price of oil to $54 a barrel with existing credits; by 2016 ethanol production increases by 56 billion liters. This model predicts an extra 10.816 million hectares of cultivated crops, distributed across a number of countries, in particular Brazil, China, India, and the U.S. No attribution of new cultivation to type of land possible with this model.
Second Step: Determine which type of land in each country is used in this extra production. Model used percentages of different land types converted to cultivation in each country during the years 1990-1999. Assumption is that these percentages remain the same.
Third Step: Estimate the amount of carbon in vegetation and soils for each type of forest or grassland and calculate emissions from agricultural conversion for each type. Model: Woods Hole Research Center data was compiled for conversions of different ecosystems. The emissions calculation assumed the loss of 25% of the carbon in the top meter of soils, and the loss of all carbon in vegetation through burning or decomposition. They calculated a weighted average of the emissions associated with each ecosystem type in each region to produce an average emission cost per hectare. This calculation primarily consists of up-front conversion emissions spread out over 30 years, but also includes carbon sequestration that will not occur on otherwise re-growing forests over 30 years. These calculations yield a weighted average level of carbon emissions for each hectare in each region which is converted from pure carbon

to CO2 emissions. These factors are multiplied by extra hectares of land per country. This is an estimate of the carbon loss due to extra land in production as a consequence of 55.92 billion additional liters of corn-based ethanol produced in the U.S. The following table from that study summarizes these results.

Table D-11—Estimated Carbon Emission Per Hectare by Region for Regions with Net Conversion of Forest and Grassland to Cropland in 1990s, Compiling Data from Tables D1-10*

Region	Ecosystem unit	Clearing by ecosystem (% of total)	Vegetation C + 25% of soil C† (Tonnes C/ha)	30 years of uptake existing forests (Tonnes C/ha)	Total foregone carbon tons C/hectare (Tonnes C/ha)	Weighted average rate for areas with net conversion‡ *(Tonnes CO2 equivalent/ha)*
Pacific Developed	TEMPEF	0.00%	193.5	71.41703	264.9	
	TEMPDF	0.00%	168.5	56.71445	225.2	
	TROPMF	15.17%	229.25	2.81342	232.1	
	TROPGL	59.80%	28.5	0	28.5	
	TROPW	25.04%	44.25	0	44.3	
	Weighted average	100.00%	62.88917	0.4266838	65.7	241.119
North Africa/Middle East	TEMPEF	0.00%	193.5	63.77011	257.3	
	TROPMF	0.00%	229.25	87.10571	316.4	
	TROPGL	49.82%	28.5	0	28.5	
	DESCRB	40.00%	17.5	0	17.5	
	TROPW	10.18%	44.25	0	44.3	
	Weighted average	100.00%	25.70368	0	25.7	94.319
Canada	TEMPEF	19.82%	193.5	14.85477	208.4	
	TEMPDF	0.00%	168.5	1.92416	170.4	
	BORLF	0.00%	141.5	1.15447	142.7	
	TEMPGL	80.18%	54.25	0	54.3	
	TUNDRA	0.00%	46.25	0	46.3	
	Weighted average	100.00%	81.8491	2.9441887	84.842343	311.3714
United States	Broadleaf forest	1.62%	187.5	19.07674	206.6	
	Mixed forest	34.42%	210	12.38175	222.4	
	Woodland	0.00%	112.5	1.66229	114.2	
	Coniferous/ Mountain	0.00%	175	0	175	
	Coniferous pacific	2.32%	240	24.28481	264.3	
	Chaparral	0.00%	60	0	60	
	Grassland	61.64%	30	0	30	
	Weighted average	100.00%	99.38239	5.1343882	104.5238	383.60236

Source: Use of U.S. Cropland for Biofuels Increases Greenhouse Gases from Land Use Change. Science Express 319, pp. 1238-1240, February 2008. Supporting on-line material.

7.2 California Air Resources Board

(CARB - http://www.arb.ca.gov/fuels/lcfs/lcfs.htm)

First step: Estimate area of extra land . Model: GTAP, computable general equilibrium, version 6 (as of 2008), validated with simulation for years 2001-2006 data, 2006 benchmark, simulated for 2006-2015. Includes markets for ethanol co-products.
Second Step: Determine which type of land in each country is used in this extra

production. Model: GTAP-AEZ (augmented GTAP with land use module AEZ - Agro-Ecological Zones.) Disaggregates land use into 18 AEZs which share common climate, precipitation and moisture conditions. Land use competition is modeled using the Constant Elasticity of Transformation (CET) revenue function, which postulates that land owners maximize total returns by allocating their land endowment to different uses subject to limitations on land use change. Assumption of homothetic weak separability in land supplies is made, allowing division of the allocation problem into two parts. In the first, the landowner allocates land cover across three different types—crop, pasture, and accessible forestry. Conditional on the total availability of land for crop production, the next CET nest determines its allocation across crops. At each stage, the econometrically-based elasticity of transformation differs.

The global land use data base has four key pieces. The data on land cover distinguishing global land cover by type, including built-up land as well as non-commercial land. For purposes of this study, they only use the forest, pastureland and cropland cover types. Other land uses are assumed to be invariant to biofuels policies. Data on harvested land cover and yields has its origins in the AgroMaps data base project of FAO, IFPRI and SAGE, which assembled county-level data for all countries of the world and mapped these to 0.5 degree grid cells. These two data bases are aggregated to the 18 AEZ level prior to their incorporation into the GTAP data base. The third land use data base maps forestry activity to the forest land cover in the 18 AEZs. Assembling all of these pieces produced a GTAP-compatible global land use data base at the AEZ level. This involves disaggregating land rents in the GTAP data base on the basis of prices and yields. This final product is the one used in the present study. Key econometric parameters obtained from different sources.

The following tables from their reports summarize results from the GTAP simulation.

Table 8. Decomposition of Land Cover Change by EU and US Biofuel Mandates (with Sensitivity Analysis): 2006-15 (% ch)

	Crop Cover					Forest Cover					Pasture Cover				
	USEU 2015	US 2015	EU 2015	Confidence Interval (95%)		USEU 2015	US 2015	EU 2015	Confidence Interval (95%)		USEU 2015	US 2015	EU 2015	Confidence Interval (95%)	
				Lower	Upper				Lower	Upper				Lower	Upper
US	0.69*	0.39	0.30	0.37	1.00	-2.46*	-1.46	-1.00	-3.60	-1.35	-3.79*	-2.04	-1.75	-5.56	-2.02
Canada	2.82*	0.76	2.06	1.43	4.27	-2.57*	-0.69	-1.88	-4.00	-1.30	-4.41*	-1.16	-3.25	-6.78	-2.04
EU-27	2.13*	0.16	1.97	1.16	3.03	-8.21*	-0.64	-7.57	-11.41	-4.82	-9.45*	-0.74	-8.71	-12.80	-6.10
Brazil	2.85*	1.90	0.94	1.52	4.13	-9.22*	-6.64	-2.58	-13.19	-5.38	-9.69*	-6.16	-3.53	-13.94	-5.44
Japan	0.30	0.10	0.20	0.03	0.63	-0.68	-0.23	-0.45	-1.53	0.03	-1.16*	-0.37	-0.79	-2.06	-0.27
China-Hong Kong	0.03	0.02	0.00	-0.05	0.13	0.08	-0.08	0.16	-0.40	0.44	-0.74	-0.18	-0.56	-1.46	-0.01
India	0.07	0.01	0.06	-0.03	0.20	-0.02	-0.01	-0.01	-0.48	0.32	-0.35	-0.03	-0.32	-0.84	0.14
Latin American EEx.	0.62*	0.21	0.41	0.25	1.02	-1.21*	-0.44	-0.77	-2.05	-0.47	-1.69*	-0.54	-1.15	-2.81	-0.57
Rest of Latin Am.	0.48*	0.12	0.37	0.18	0.81	-0.28	-0.22	-0.06	-1.24	0.64	-1.89*	-0.40	-1.50	-3.10	-0.69
EE & FSU EEx.	0.59*	0.17	0.42	0.19	1.02	-0.54	-0.30	-0.25	-1.79	0.58	-2.81*	-0.61	-2.20	-4.53	-1.09
Rest of Europe	1.13*	0.26	0.87	0.48	1.79	-0.90	-0.34	-0.56	-2.00	0.14	-2.49*	-0.44	-2.05	-3.93	-1.05
Middle Eastern N Africa EEx.	0.41*	0.10	0.31	0.11	0.74	-0.96	-0.24	-0.72	-1.95	-0.07	-1.55*	-0.38	-1.17	-2.65	-0.45
Sub Saharan EEx.	1.26*	0.34	0.92	0.48	2.11	-0.71*	-0.19	-0.52	-1.31	-0.18	-2.08*	-0.55	-1.53	-3.23	-0.93
Rest of Africa	1.49*	0.32	1.17	0.67	2.31	-1.58*	-0.37	-1.21	-2.59	-0.60	-2.93*	-0.58	-2.35	-4.57	-1.29
South Asian EEx.	-0.06	0.00	-0.06	-0.18	0.07	0.32	0.04	0.28	-0.20	0.81	-0.54*	-0.14	-0.40	-1.02	-0.05
Rest of High Income Asia	0.00	0.01	0.00	-0.02	0.03	0.44	0.03	0.41	-0.11	0.94	-0.71*	-0.26	-0.45	-1.31	-0.11
Rest of Southeast & South Asia	0.04	0.01	0.04	-0.01	0.11	-0.05	-0.01	-0.04	-0.42	0.26	-0.52	-0.08	-0.43	-1.09	0.06
Oceania countries	0.89*	0.21	0.68	0.34	1.46	-0.81*	-0.23	-0.58	-1.35	-0.32	-1.19*	-0.26	-0.93	-2.01	-0.37

Note: USEU2015 policy impact is decomposed into US2015 and EU2015 effects. The confidence intervals pertain to the USEU2015 combined impact.
* indicates that mean values are larger than twice the standard deviations from zero, implying a significant range of impact.

Source: "Biofuels for All?," Thomas W. Hertel, Wallace E. Tyner and Dileep K. Birur, GTAP working paper 4146, 2008.

Table 5. Percentage Changes in Land Demand Following One Billion Gallon Increase in Ethanol Demand in the United States

Region	Coarse Grains	Oilseeds	Sugarcane	Other Grains	Other Agriculture
USA	1.66	−1.14	−0.64	−1.31	−0.34
	(0.15)	(0.16)	(0.15)	(0.22)	(0.13)
Brazil	0.33	0.09	0.55	−0.18	−0.15
	(0.41)	(0.77)	(0.05)	(0.19)	(0.12)
Canada	0.84	0.32	−0.09	−0.08	−0.05
	(0.28)	(0.43)	(0.33)	(0.60)	(0.45)
China (HK)	0.24	0.18	−0.02	−0.01	−0.02
	(0.40)	(0.33)	(0.17)	(0.67)	(0.20)
Eur. Union	0.15	−0.03	−0.03	−0.02	−0.01
	(0.47)	(1.38)	(0.42)	(1.49)	(2.10)
India	0.00	0.02	−0.02	0.01	0.00
	(2.33)	(0.42)	(0.22)	(0.61)	(0.81)
Japan	1.28	0.20	−0.02	0.04	−0.01
	(0.20)	(0.32)	(0.24)	(0.50)	(0.35)
E. Eur. & FSU Ex.	0.09	0.18	−0.01	0.03	0.00
	(0.48)	(0.31)	(0.46)	(0.62)	(15.55)
Lat. Amer. Ex.	0.42	0.11	−0.14	−0.11	−0.08
	(0.27)	(0.85)	(0.17)	(0.39)	(0.24)
M. East. No. Afr. Ex.	0.43	0.13	−0.04	0.06	−0.02
	(0.33)	(0.33)	(0.15)	(0.52)	(0.32)
Oceania	0.63	0.21	−0.01	−0.03	−0.02
	(0.22)	(0.50)	(1.28)	(0.66)	(0.41)
R. Africa	0.39	0.14	−0.04	0.00	−0.01
	(0.32)	(0.49)	(0.41)	(17.56)	(1.17)
R. Asia	0.08	0.10	−0.03	0.00	−0.01
	(0.53)	(0.33)	(0.18)	(2.63)	(0.33)
R. Europe	0.30	0.10	0.00	0.07	0.01
	(0.34)	(0.37)	(11.91)	(0.48)	(0.94)
R. High Inc. Asia	0.54	0.22	−0.01	0.00	−0.01
	(0.34)	(0.39)	(0.30)	(1.58)	(0.36)
R. Lat Amer.	0.50	0.12	−0.06	0.00	−0.03
	(0.29)	(0.47)	(0.15)	(28.95)	(0.26)
So. Asia. Ex.	0.13	0.16	−0.03	−0.01	−0.01
	(0.48)	(0.34)	(0.16)	(0.32)	(0.35)
Sub-Saharan Ex.	0.03	0.16	0.00	0.07	0.02
	(0.93)	(0.35)	(2.75)	(0.41)	(0.44)

Note: Source is authors' simulations. Coefficients of variation are in parentheses. Land-use changes reported are productivity (rental) weighted changes in land use: $\sum_{j \in AEZ} \Omega_{j,i} x_{j,i}$ where $\Omega_{j,i}$ is the share of land rents in AEZ j in total land rents for crop type i.

Table 6. Percentage Changes in Land Cover Following One Billion Gallon Increase in Ethanol Demand in the United States

Region	Forest Cover	Pasture Cover	Cropland Cover
USA	−0.35	−0.53	0.10
	(0.29)	(0.27)	(0.28)
Brazil	−0.16	−0.17	0.08
	(0.25)	(0.26)	(0.26)
Canada	−0.10	−0.17	0.14
	(0.27)	(0.29)	(0.27)
China (HK)	−0.01	−0.02	0.00
	(0.46)	(0.44)	(0.44)
Eur. Union	−0.09	−0.11	0.03
	(0.34)	(0.34)	(0.34)
India	−0.01	−0.01	0.00
	(0.57)	(0.52)	(0.52)
Japan	−0.03	−0.07	0.02
	(0.43)	(0.28)	(0.36)
E. Eur. & FSU Ex.	−0.03	−0.07	0.02
	(0.33)	(0.32)	(0.30)
Lat. Amer. Ex.	−0.08	−0.08	0.04
	(0.31)	(0.34)	(0.33)
M. East. No. Afr. Ex.	−0.04	−0.06	0.02
	(0.37)	(0.32)	(0.34)
Oceania	−0.04	−0.04	0.03
	(0.27)	(0.37)	(0.34)
R. Africa	−0.06	−0.10	0.06
	(0.30)	(0.30)	(0.30)
R. Asia	−0.01	−0.02	0.00
	(0.43)	(0.48)	(0.46)
R. Europe	−0.04	−0.05	0.03
	(0.29)	(0.31)	(0.29)
R. High Inc. Asia	0.00	−0.04	0.00
	(2.70)	(0.25)	(0.28)
R. Lat Amer.	−0.04	−0.06	0.02
	(0.32)	(0.34)	(0.34)
So. Asia. Ex.	0.00	−0.01	0.00
	(5.33)	(0.53)	(2.11)
Sub-Saharan Ex.	−0.02	−0.04	0.03
	(0.33)	(0.30)	(0.32)

Note: Source is authors' simulations. Coefficients of variation are in parentheses. Land-use changes reported are productivity (rental) weighted changes in land use: $\sum_{j \in AEZ} \Omega_{ij} x_{ij}$ where Ω_{ij} is the share of land rents in AEZ j in total land rents for land cover type i.

Source: "The Indirect land Use Impacts of United States Biofuels Policies: The importance of acreage, yield, and bilateral trade responses," R. Keeney and T, Hertel, *AJAE,* 91(4), November 2009, pp 895-909.

Third step: Estimate the amount of carbon in vegetation and soils for each type of forest or grassland and calculate emissions from agricultural conversion for each type. Model: Woods Hole Research Center, data compiled for conversions of different ecosystems. Same as in Searchinger et al., as described above.

7.3 EPA (http://www.epa.gov/OMS/renewablefuels/)

First step: Estimate area of extra land. Model: FASOM linear programming model for domestic land changes and FAPRI econometric model for international land changes. They identify crop acreage by country and by crop. Both models include markets for distillers' grains (they assume 1 pound of co-product displaces 1 pound of feed), domestic yields are from USDA's projections to 2022, international yields are from historical trends and are lower than the domestic ones. No changes in productivity due to shifts in marginal lands or to price induced productivity effects included. FASOM only measures shifts in the use of existing cropland and pastureland but not new additions. They are also working with GTAP but no results are public at this time.
Second Step: Determine which type of land in each country is used in this extra production. Model: For the domestic portion FASOM includes market for different land types, in which allocations depend on returns and specific rental rates. Sixty three regions are included. Forestland was excluded in these preliminary calculations, but reallocation of land across different crops and between crops and pasture is allowed. For the international portion, area is allocated according to historical patterns as identified by satellite images (MODIS). This approach is referred to here as the FAPRI/Winrock approach because it relies on the integration of these two tools.

Using satellite data from 2001–2004, Winrock provided a breakdown of the types of land that have been converted into cropland for a number of key agriculturally producing countries based on the International Geosphere-Biosphere Programme (IGBP). The IGBP land cover list includes eleven classes of natural vegetation, three classes of developed and mosaic lands, and three classes of non-vegetated lands. The natural vegetation units distinguish evergreen and deciduous, broadleaf and needle-leaf forests, mixed forests, where mixtures occur; closed shrublands and open shrublands; savannas and woody savannas; grasslands; and permanent wetlands of large areal extent. The three classes of developed and mosaic lands distinguish among croplands, urban and built-up lands, and cropland/natural vegetation mosaics. Classes of non-vegetated land cover units include snow and ice; barren land; and water bodies. Winrock aggregated these categories into five similar classes: five classes of forest were combined into one, two classes of savanna were combined into one, and two classes of shrubland were combined into one. The final land cover categories for this analysis are forest, cropland, grassland, savanna, and shrubland.

The EPA approach does not distinguish between land-use changes associated with one crop versus another. Land use trends and emissions factors were estimated for ten countries including Argentina, Brazil, China, India, Indonesia, Malaysia, Mexico, Philippines, EU and South Africa. The 17 MODIS imagery land cover classes were reclassified using the International Geosphere Biosphere Programme land cover dataset into five general classes: cropland, forest, grassland, savanna and shrubland as shown in the following table.

TABLE VI.B.5–1—TYPES OF LAND CONVERTED TO CROPLAND BY COUNTRY

[In percent]

Country	Forest	Grassland	Savanna	Shrub
Argentina	8	40	45	8
Brazil	4	18	74	4
China	17	38	23	21
EU	27	16	36	21
India	7	7	33	53
Indonesia	34	5	58	4
Malaysia	74	3	19	3
Nigeria	4	56	36	4
Philippines	49	5	44	3
South Africa	10	22	53	15

Source: Winrock Satellite Data (2001–2004).

Third step: Estimate the amount of carbon in vegetation and soils for each type of forest or grassland and calculate emissions from agricultural conversion for each type. Model: estimates of domestic land use change GHG emissions are based on outputs of the FASOM model. FASOM explicitly models change in soil carbon from increased crop production acres and from different types of crop production. FASOM also models changes in soil carbon from converting non crop land into crop production. For the international impacts, they used the 2006 IPCC Agriculture, Forestry, and Other Land Use (AFOLU) Guidelines and Winrock, who provided GHG emissions factors for each country based on the weighted average type of land converted.

GHG emissions estimates were based on immediate releases (e.g., changes in biomass carbon stocks, soil carbon stocks, and non-CO2 emissions assuming the land is cleared with fire) and foregone forest sequestration (the future growth in vegetation and soil carbon). Carbon soil calculations take into account the annual changes in carbon content in the top 30 centimeters of soil over the first 20 years, based on IPCC recommendations. Where country specific emission factors were not available in time for their proposal, world average was used.

The following tables summarize preliminary results that have been released.

Table 2.6-38.
Regional Land Conversion GHG Emissions Factors
Undiscounted Emissions Over 80 Years
(MTCO2-eq. / acre)

Country / Region	To	From: Forest	Grassland	Savanna	Shrub
Argentina	Crop	115	16	17	33
	Grassland	136			15
	Savanna	129			9
Brazil	Crop	258	45	60	82
	Grassland	257			39
	Savanna	240			26
China	Crop	237	23	34	40
	Grassland	186			27
	Savanna	240			27
European Union	Crop	318	28	38	47
	Grassland	216			22
	Savanna	181			14
India	Crop	247	26	26	38
	Grassland	249			249
	Savanna	236			12
Indonesia	Crop	432	43	51	94
	Grassland	455			51
	Savanna	415			42
Malaysia	Crop	473	50	57	103
	Grassland	457			51
	Savanna	438			42
Nigeria	Crop	96	18	23	78
	Grassland	92			58
	Savanna	112			28
Philippines	Crop	402	34	44	88
	Grassland	371			51
	Savanna	359			42
South Africa	Crop	111	18	36	79
	Grassland	109			58
	Savanna	86			47

Table 2.6-39.
Regional Weighted Average Emissions Factors (WAEF)
(MTCO2-eq. per acre of crop expansion)

Country / Region	Crop Expansion	Pasture Replacement	Total WAEF
Argentina	25	34	60
Brazil	66	76	142
China	68	45	113
European Union	106	41	147
India	48	33	81
Indonesia	182	60	242
Malaysia	367	93	461
Nigeria	25	31	56
Philippines	219	170	389
South Africa	47	32	79

Source: Draft Regulatory Impact Analysis RSF2, EPA.
http://www.epa.gov/OMS/renewablefuels/420d09001.pdf

7.4 Hertel et al. Bioscience, 2010

First step: Estimate area of extra land. Model: GTAP-BIO (Hertel, Tyner et al. 2010) which is a modification of GTAP-E to include land market response. Global changes in land use due to expansion of U.S. grown corn for ethanol is obtained.
Second step: Increases in land allocated across agroecological zones, Model: GTAP that incorporates Agro-Ecological Zones (AEZs) Hertel et al. (2009), this version identifies land-cover changes within 18 AEZs defined by rainfall and temperature (Lee et al., 2009), as well as 18 trading regions. Provides estimates of changes in area dedicated to forestry, pasture and cropping by AEZs.
Third Step: Estimate amount of carbon in vegetation and soils for each type of forest or grassland converted as well as calculate emissions for each. Same as in Searchinger et al. and in earlier versions of GTAP. Model: Woods Hole Research Center.

Shock is the expansion of US maize ethanol use from 2001 levels to the 2015 mandated level of 56.7 gigaliters (GL) per year by forcing 50.15 GL of additional ethanol production, with the higher costs passed forward to consumers in the form of higher fuel prices. Then they evaluate the change in US coarse grains prices due to the 50GL per year ethanol increase.
Departures from Searchinger et al.:
Increase in cultivated land associated with U.S. based maize ethanol is two-fifths of the amount estimated by Searchinger et al.

The estimated Greenhouse Gas Emissions (GHG) release is 870 tetragrams of CO2 emissions, or 800 g of carbon dioxide per MJ of increased annual ethanol production. Following Searchinger et al., the amortization over 30 years of production at current yields results in ILUC emissions of **27 grams CO2 per MJ** (about one-fourth the value estimated by Searchinger et al.). The emission factors are developed and they account for changes in above-and belowground carbon stocks and changes in 30-year carbon sequestration by ecosystems that are gaining carbon. Data used are compiled by the Woods Hole Research Institute.

The authors modify Searchinger et al.'s approach as follow: (i) they assume that 10% of forest biomass is sequestered in either timber products or charcoal in soil, and that the remaining 90% is oxidized to CO2; (ii) The authors ignore non-CO2 emissions; (iii) Searchinger calculates a single emission factor for all conversion to cropland in a particular region. The authors determine separate emission factors for each of the dominant transitions predicted by GTAP (forest to cropland, pasture to cropland, and pasture to forest).

Supporting material below from Hertel et al. 2009, on line report, http://www.aibs.org/bioscience-press-releases/resources/Hertel.pdf. Table 1 reports land cover changes (Mha) in all regions of the world.

US vs. Rest of World (non-US regions)

Land cover type	US	ROW
cropland	1.59	2.6
pasture	1.05	-2.35
forest	- 0.54	-0.25

ROW disaggregated

	Canada	EU	Brazil	Japan	China
cropland	0.45	0.45	0.30	0.01	0.04
pasture	-0.15	-0.16	-0.24	0.00	-0.13
forest	-0.29	-0.29	-0.06	-0.01	0.09

ROW

	India	LAEn Exp	RofLatAme rica	EEuropeFSU	RofEurope	MENA
cropland	0.05	0.18	0.06	0.16	0.07	0.08
pasture	-0.02	-0.18	-0.14	-0.44	-0.05	-0.08
forest	-0.03	0.00	0.08	0.27	-0.02	0.00

ROW

	SSAEnExp	RofS SA	SASIAEEX	RoHIA	RoASIA	Oceania
cropland	0.54	0.09	-0.01	0.00	0.03	0.11
pasture	-0.53	-0.09	-0.01	0.00	-0.02	-0.11
forest	-0.01	0.00	0.03	0.00	-0.01	0.00

Source: Authors' Calculations

Table 2 below reports the authors' findings for GHG:
The first row reports their base case results of 799 g CO2 MJ-1.

The second row reports the case where they set the yield elasticity at its highest value (0.5) and ETA[5] at its highest value (1.0) as well, thus maximizing the potential for yields to offset the increased biofuels requirements and gives result of 444 g CO2 MJ-1. The third column is the case where the potential for yield response to price is eliminated, and set ETA at is lower bound of 0.32. The estimated global emissions rate is of 2702 g CO2 MJ-1.

The last two rows report the outcomes when other elements of the market-mediated responses are not taken into account. In the first case, they eliminate the

[5] Central value for the parameter

potential for livestock sectors to substitute co-products for other feedstuffs. This gives a result of 1,285 g CO2 MJ-1. In the second case, they report the case where they hold food consumption constant globally via a set of commodity/region specific subsidies. With food consumption failing to drop, global emissions rise by 41% above the base.

Base case	799
Low LUC	444
High LUC	2702
No Coproducts	1285
Constant Food Consumption	1127

7.5 Melillo et al. 2009a, Science

Expansion of global cellulosic biofuels program. Global modeling system that integrates land-use change as driven by multiple demands for land and that includes dynamic greenhouse gas accounting. The modeling system consists of a computable general equilibrium model of the world economy combined with a process based terrestrial biogeochemistry model. This allows for generating global land-use scenarios and explores some of the environmental consequences of an expanded global cellulosic biofuels program over the 21st century.

Two cases considered. Case 1 allows conversion of natural areas to meet increased demand for land and conversion costs are covered by returns. Case 2 allows less conversion by incorporating regional land-conversion-response elasticities that reflect the observed rate of land conversion over the past decade. In this case, economic forces drive more intensification of existing managed land.

First step: Model: MIT Emissions Predictions and Policy Analysis (EPPA). The MIT EPPA model is a recursive-dynamic multi-regional computable general equilibrium model of the world economy. The model is based on the GTAP data base with the aggregated into 16 regions and 25 sectors. The model also incorporates U.S. Environmental Protection Agency inventory data and projections on greenhouse gas and air pollutant emissions to estimate anthropogenic emissions of these compounds. The EPPA model projects the global economy, land use, and associated anthropogenic emissions into the future using a 5-year time step.

Second Step: Model: Terrestrial Ecosystem Model (TEM). The TEM is a process-based ecosystem model that uses spatially referenced information on climate, elevation, soils, vegetation and water availability to estimate monthly vegetation and soil carbon and nitrogen fluxes and pool sizes. This model has been used to examine patterns of land carbon dynamics across the globe including how they are influenced by multiple factors such as CO2, fertilization, climate change and variability, land-use change, and ozone pollution. The distribution of TEM cohorts during the year 2000 is used as the initial land cover for developing future land use scenarios using changes in EPPA land shares

Third step: Link TEM estimates to each class/region of the EPPA model by assigning a unit price based on a comparison of the distribution of land cover in 1997 as described

by the Hurtt et al. data set to the corresponding GTAP land-value data of cropland, pasture, and managed forests. The unit price of each land type is then used to determine changes in the land area required to support future market demand for food, biofuels and wood products based on associated changes in land value
Data: Supporting data for land cover (case 1 and case 2), and carbon fluxes and N fertilizer application from 2000 to 2100 Simulation to assess the direct and indirect effects of a global biofuels program on greenhouse gas emissions can be accessed at http://globalchange.mit.edu/pubs/abstract.php?publication_id=1991

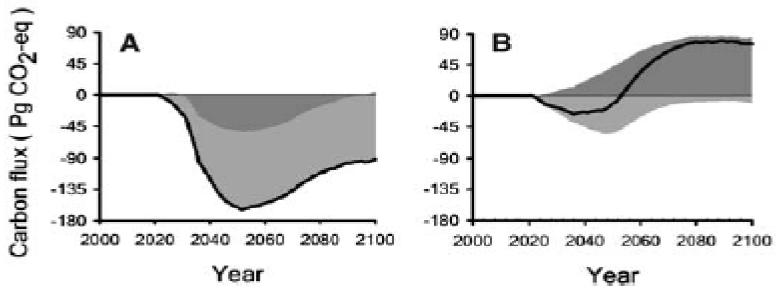


Fig. 2. Partitioning of direct (dark gray) and indirect effects (light gray) on projected cumulative land carbon flux since the year 2000 (black line) from cellulosic biofuel production for land-use case 1 (**A**) and case 2 (**B**). Positive values represent carbon sequestration, whereas negative values represent carbon emissions by land ecosystems. In case 1, the cumulative loss is 92 Pg CO_2eq by 2100, with the maximum loss (164 Pg CO_2eq) occurring in the 2050 to 2055 time frame, indirect losses of 110 Pg CO_2eq, and direct losses of 54 Pg CO_2eq. In the second half of the century, there is net accumulation of 72 Pg CO_2eq mostly in the soil in response to the use of nitrogen fertilizers. In case 2, land areas are projected to have a net accumulation of 75 Pg CO_2eq as a result of biofuel production, with maximum loss of 26 Pg CO_2eq in the 2035 to 2040 time frame, followed by substantial accumulation.

7.6 Hiederer et al. Science, 2009

http://eusoils.jrc.ec.europa.eu/ESDB_Archive/eusoils_docs/Images/EUR24483.JPG

First step: Provide soil and land use maps that identify regions where the expansion of biofuels production are most likely to occur. The study uses the results and output of agro economic models: MIRAGE (general equilibrium mode processed by IFPRI) and the AGLINK-COSIMO (partial equilibrium model processed by JRC-IPTS[6]) that predict the location where land use change occur, based on cropped areas, land availability, and land suitability.
Second step: Convert the land use changes obtained in the previous step into an estimate of GHG emissions resulting from the given change in biofuel demand. Thus, estimate of GHG emissions calculated taking as input data the results from studies using the MIRAGE and AGLINK.

Changes in land carbon stocks are translated into estimates of GHG emissions, which results from the indirect land use changes caused by the production of biofuels as modeled by agro-economic models. For the distribution of the extra land a spatial allocation procedure was developed.

[6] JRC: Joint Research Center. European Commission

The general function of the spatial allocation procedure is to distribute the marginal cropland resulting from the implementation of different biofuel policy scenarios, according to the results of the economic models run at regional level. Allocation criteria are the land suitability for agriculture and the distance from cropland. The spatial allocation of agricultural land demand is performed in two step process: spatial analysis (database creation, combining data sources into a single database); simulation (based on cropland demands from agro-economic models).
The IFPRI-MIRAGE dataset provides the land use change as a consequence of EU biofuels policy assuming first-generation land-using ethanol and biodiesel achieving a 5.6% share of transport fuel consumption in 2020. The model assumes alternative trade policy scenarios: business as usual trade policy (BAU) and full, multilateral trade liberalization in biofuels (FT).

Table 30 below presents total GHG emissions resulting from extra land demand based on IFPRI-MIRAGE and AGLINK-COSIMO model as run by JRC-IPTS.

Table 30: Total Greenhouse Gas Emissions from Changes in Soil and Biomass Carbon Stocks Induced by ILUC

Source	IFPRI BAU		IFPRI FT		IPTS CG		IPTS GM	
	Mt CO_2eq	*%*	*Mt CO_2eq*	*%*	*Mt CO_2eq*	*%*	*Mt CO_2eq*	*%*
Emissions from change in soil C stock	29	15	32	14	202	18	219	20
N_2O emissions related to loss in soil C	5	2	6	2	28	3	29	3
Emissions from change in ABCS	168	82	210	83	862	79	867	78
Total GHG emissions from land use change	201	100	248	100	1092	100	1115	100

The table below (35) summarizes the total annual emission values including emissions from LUC calculated by the JRC for the two scenarios in IFPRI-MIRAGE (BAU and FT) and IPTS-AGLINK models compared to the emissions of the fossil fuel comparator, and the savings are given in % compared to fossil fuel emissions (table 35 below).

Table 35: Annual GHG Emissions from LUC, Cultivation, Processing, Transport and Distribution of the Biofuels and Default Annual Fossil Fuel Emissions

Emission Source	Method	Crop	Annual Emissions *g CO_2eq MJ^{-1}*
Annual emissions from land use change (IFPRI BAU Scenario)		averaged over all crops	34
Annual emissions from land use change (IFPRI FT Scenario)		averaged over all crops	41
Annual emissions from land use change (IPTS)		averaged over all crops	63
"Weighted values" for annual emissions from cultivation, processing, transport and distribution of the biofuel - IFPRI MIRAGE	"Default" RED methodology	BAU scenario	34
		FT scenario	27
	JEC WTW methodology	BAU scenario	22
		FT scenario	17
Annual emissions from cultivation, processing, transport and distribution of the biofuel – JRC-IPTS AGLINK-COSIMO	"Default" RED methodology		48
	JEC WTW methodology		42
Fossil Fuel Comparator	RED methodology		**83.3**
	JEC WTW methodology		**87.0**

Table 35: Annual GHG Emissions from LUC, Cultivation, Processing, Transport and Distribution of the Biofuels and Default Annual Fossil Fuel Emissions

Emission Source	Method	Crop	Annual Emissions g $CO_2eq\ MJ^{1}$
Annual emissions from land use change (IFPRI BAU Scenario)		averaged over all crops	34
Annual emissions from land use change (IFPRI FT Scenario)		averaged over all crops	41
Annual emissions from land use change (IPTS)		averaged over all crops	63
"Weighted values" for annual emissions from cultivation, processing, transport and distribution of the biofuel - IFPRI MIRAGE	"Default" RED methodology	BAU scenario	34
		FT scenario	27
	JEC WTW methodology	BAU scenario	22
		FT scenario	17
Annual emissions from cultivation, processing, transport and distribution of the biofuel – JRC-IPTS AGLINK-COSIMO	"Default" RED methodology		48
	JEC WTW methodology		42
Fossil Fuel Comparator	RED methodology		**83.3**
	JEC WTW methodology		**87.0**

7.7 Witzke et al. 2010, IATRC Symposium, Stuttgart

http://ageconsearch.umn.edu/bitstream/91430/2/Witzke_et_al._IATRC_Summer_2010.pdf

Comparison of ILUC across different models.
First step only: change in area of land.
3 scenarios and 5 modelling systems given in Table 1.

Table 1: Scenarios and modelling systems used in the comparison

USmaize
GTAP+ 1 mtoe of ethanol based on US maize
FAPRI+ 15.8 mtoe of ethanol based on US maize
IMPACT+ 0.21 mtoe of ethanol based on US maize
GLOBIOM+ 2.6 mtoe of ethanol based on US maize
EUwheat
AGLINK+ 11.8 mtoe of ethanol, + 12.9 mtoe of biodiesel
GTAP+ 1 mtoe of ethanol based on EU wheat
FAPRI+ 0.13 mtoe of ethanol based on EU wheat
IMPACT+ 0.19 mtoe of ethanol based on EU wheat
GLOBIOM+ 2.6 mtoe of ethanol based on EU wheat
EUrape
AGLINK+ 7.3 mtoe of ethanol, + 18.6 mtoe of biodiesel
GTAP+ 1 mtoe of biodiesel based on EU oilseeds
FAPRI+ 0.22 mtoe of biodiesel based on EU rape
GLOBIOM+ 3.9 mtoe of biodiesel based on EU rape

The Global Trade Analysis Project (GTAP) model is a static CGE model with the Armington approach reflecting imperfect substitutability of products across regions. A modified version of the GTAP-BIO model (Birur, Hertel, Tyner 2008) is used in the analysis. It permits substitution among various fuels and explicitly considers DDGS and oil meals as by-products that may substitute for coarse grains and oil seeds according to an elasticity of substitution. In terms of land use it considers 19 regions each of which possibly divided into several Agro-Ecological Zones (AEZ) in order to better reflect the rigidities imposed by natural conditions. Crops were aggregated to 6 products (wheat, rice, coarse grains, oil fruits, sugar plants, others) that also provided the common denominator for this analysis. The simulations were for year 2001, using the version 6 GTAP database.

The FAPRI modelling system (version operated at CARD, Iowa) is a set of recursive dynamic partial equilibrium models covering the (15) major crops (from an US perspective) and some 50 regions, depending on the product. The system is well known for its econometric underpinnings, but calibration approaches are also used where needed. Bio-ethanol and bio-diesel are explicitly represented together with related policy instruments. DDG may displace other feed according to displacement rates, adoption rates and inclusion rates specific for animal types. Oils meals are a standard feed input linked to the oilseeds sector and animal markets. The trade representation (explicit policy instruments or price transmission elasticities) varies according to the importance of regions. Whereas the EU scenarios are based on the 2009 model version and run to year 2023 the US ethanol scenario is from 2008 (Hayes et al. 2009), running to year 2022. In this context the most important updates of the 2009 model version refer to the yield specification and a more complete DDGS acknowledgement in non-US regions (see Annex 2 in document).

The International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) from IFPRI has a stronger focus on developing country issues and water scarcity. There are 20 crops and about 115 market regions (mostly countries2), each of which possibly divided into several water catchment areas on the supply side. Irrigated and rainfed production is distinguished. The model has a strong focus on long run projections and technology improvements whereas trade policies are represented in simplified form (net trade model with uniform world market price). The “other” demand component was exogenously shifted in these scenarios to mimic the shock of additional feedstock demand for bio-fuel production, but by-products are not represented. Simulations were for the years 2010-2015.

The AGLINK-COSIMO3 model is a joint OECD-FAO dynamic, partial equilibrium modeling tool with a strong tradition of projections and scenario analysis. About 10 crops have been used (knowing that separate coarse grains or oilseeds would require aggregation anyway) and a medium level regional breakdown (20 regions). Similar to the FAPRI model many equations are econometrically estimated and there is a detailed coverage of bioethanol including displacement rates for ruminants and non-ruminants (OECD 2008). This paper could not rely on the detailed model results from the marginal simulations for the above mentioned JRC report. Instead it benefitted from selective access to scenario results prepared at the IPTS, Seville for other purposes. As a consequence the AGLINK scenarios represent two versions of EU biofuel policies that involve both additional ethanol and bio-diesel demand. The scenario with a higher share of ethanol is attributed to the “EUwheat” group, but this is clearly not a marginal shock of one feedstock only. Results are presented for the year 2020.

The Global Biomass Optimization Model (GLOBIOM) is a global recursive dynamic partial equilibrium model covering agricultural and forestry sectors as well as dedicated biomass plants (Havlik et al. 2010). It is a huge linear programming model maximizing the sum of producer and consumer surplus to find the market equilibrium subject to resource constraints in the Takayama-Judge tradition. This analysis used 28 market region and 18 crops. Supply side modelling is based on up to 200 000 ‘simulation units’, but for the simulations presented here, an aggregation to about 6000 supply regions was used, defined from an overlay of country borders, soil, slope, and altitude information. For each of these there are 4 management options permitting an endogenous choice of yields. Bio-diesel and ethanol from oilseeds and cereals are included, with displacement ratios for DDGS non-specific to animal types, as the version used here only included the animal sector in aggregate form. Simulations results are given for 2020. The size of the shock has been chosen somewhat larger than in the marginal calculations commissioned for the JRC to trigger some changes in management options.

Many relevant models have been excluded from this comparison. Both DART and CAPRI are currently improved to better prepare them for similar analyses of LUC on the global level. LEITAP and MIRAGE have been discarded for lack of time, just to mention a few other well known modeling systems that have already addressed bio-fuel scenarios.

Table 13 below presents a summary of the results of this exercise.

Table 13: Global land use change under three biofuel scenarios according to several modelling systems (per 1 mtoe and normalised to year 2020 yields)

	Additional land demand (>0) or land savings (<0) due to changes in…						
	biofuel feedstocks	other domestic use	net exports	crop yields	sum total		
			US maize				
GTAP	457 =100%	-68%	13%	-20%	26%	=	118
FAPRI	398 =100%	-79%	63%	-3%	81%	=	323
IMPACT	387 =100%	-129%	164%	-110%	26%	=	99
GLOBIOM	544 =100%	-63%	-3%	47%	81%	=	440
			EU wheat				
AGLINK	521 =100%	-72%	35%	-10%	53%	=	275
GTAP	885 =100%	-57%	36%	-3%	76%	=	669
FAPRI	950 =100%	-48%	11%	-7%	57%	=	540
IMPACT	1189 =100%	-78%	43%	-47%	19%	=	226
GLOBIOM	437 =100%	-12%	-51%	36%	74%	=	321
			EU Rape				
AGLINK	679 =100%	-94%	39%	-9%	36%	=	243
GTAP	803 =100%	-54%	12%	-24%	35%	=	278
FAPRI	944 =100%	-50%	10%	-13%	46%	=	435
GLOBIOM	919 =100%	-29%	7%	-20%	58%	=	533

7.8 Edwards, et al., 2010, JRC Scientific and Technical Reports

http://ec.europa.eu/energy/renewables/consultations/doc/public_consultation_iluc/study_4_iluc_modelling_comparison.pdf

This study compares the ILUC results produced by different economic models for marginal increases in biofuel production from different feedstocks. The work is the result of a survey of marginal calculations launched by the JRC-IE during 2009, involving some of the best known models worldwide.

The partial and full equilibrium models compared in this study are:

- AGLINK-COSIMO (from OECD)
- CARD (from FAPRI-ISU)1
- IMPACT (from IFPRI)
- G-TAP (from Purdue University)
- LEI-TAP (from LEI)
- CAPRI (from LEI)

An overview of the key modelling parameters of the models used for these calculations is presented in chapter 5 of the report.

The modellers were requested by JRC-IE to run scenarios corresponding as closely as possible to the following specification (e.g. marginal runs against existing baseline of the following scenarios):

A marginal extra ethanol demand in EU

B marginal extra biodiesel demand in EU
C marginal extra ethanol demand in US
D marginal extra palm oil demand in EU (for biodiesel or pure plant oil use)

The results from the different models and various scenarios are compared in this report in terms of hectares of ILUC, because all of the models produced data at that level. To enable direct comparison of the results reported by the modellers JRC-IE standardized the results to kHa per Mtoe biofuels (Million tons of oil equivalent).

Model Linearity

One expects that the area of extra cropland per extra ton-of-oil-equivalent (toe) of a particular biofuel should rise faster as the extra demand increases. That is because in general one expects that quality of the new land to decline as more is taken, and that yield increase will show diminishing returns to increasing spending. However, most models are linear in practice: they show changes in crop area which are roughly proportional to the extra demand for a particular biofuel. This is largely because econometric data is too scattered to allow calibration of non-linear behavior. Only in the case of GTAP, the marginal ha/toe of LUC increases slightly with increasing biofuels demand. This becomes more noticeable if the ratio of marginal to average crop yield is reduced, for example from 0.65 for US production to 0.5, which indicates the non-linearity depends on the amount of extra area.

Non-linearity in IFPRI-MIRAGE model

However, this is not the main cause of the strong non-linearity of results for increasing EU biofuel targets from the IFPRI-MIRAGE study commissioned by DG-TRADE. As the target for first generation EU biofuels is increased, the model forecasts a shift of marginal EU-biofuel mix from mostly extra sugar-cane ethanol to mostly extra biodiesel. As the model finds greater emissions-per ton for biodiesel than sugar-cane ethanol, the emissions per toe biofuel increases as the overall target increases.

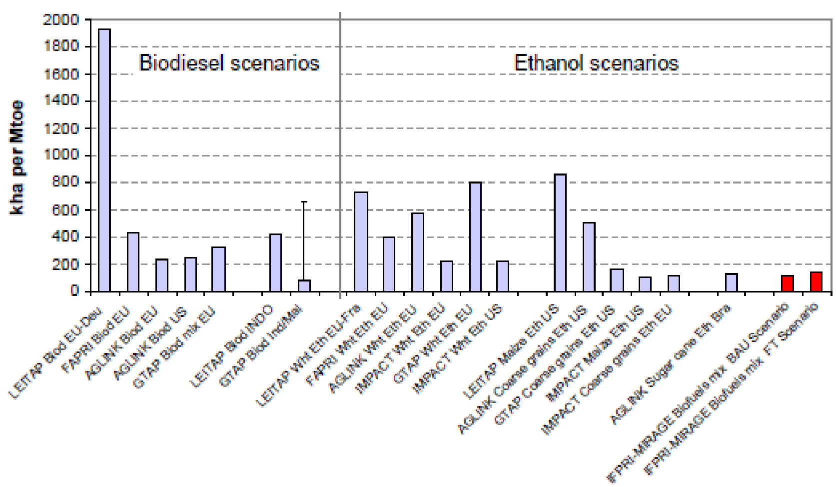
Marginal Scenarios

Since models are roughly linear, it makes sense to calculate the marginal land use change in terms of hectares per ton for particular biofuels;

- in order to compare the results for different biofuels in the same model
- in order to compare the results for the same biofuels in the same model of different models for the same size of shock
- in order to see to what extent LUC depends on the type of biofuel, and to what extent it
depends on the region the shock occurs.
- to potentially form the basis for specifying “ILUC factors” for incorporation in policy

Overall results in hectares per toe

In the EU ethanol scenarios, the total estimated ILUC (in the world) ranges from 223 to 743 kHa per Mtoe. For most of the EU ethanol scenarios the models project that the largest share of ILUC would occur outside the EU, with the exceptions of the FAPRI scenario that forces all production to come from within the EU, and the LEITAP model. In the EU biodiesel scenarios, total ILUC ranges from 242 to 1928 kHa per Mtoe with the highest value coming from the LEITAP scenario for EU biodiesel in Germany. In all of the EU biodiesel scenarios the models project that the largest share of LUC would occur outside the EU. In the US ethanol scenarios total ILUC ranges from 107 to 863 kHa per Mtoe. The AGLINK-COSIMO model and GTAP models project that most of the ILUC would occur outside the US. However, in contrast the LEITAP model projected that 90% of the ILUC would occur within the US. In the extra palm oil scenarios (only modelled by LEITAP and GTAP), the two models projected a range of ILUC from 103 to 425 kHa per Mtoe. In the LEITAP model all of the ILUC would occur in Indonesia, whilst in the GTAP model the largest share would occur outside the Malaysia/Indonesia region. The AGLINK-COSIMO model was the only model to report for extra ethanol from Brazilian sugar cane. The model projected LUC of 134 kHa per Mtoe with all of the ILUC occurring in Brazil.

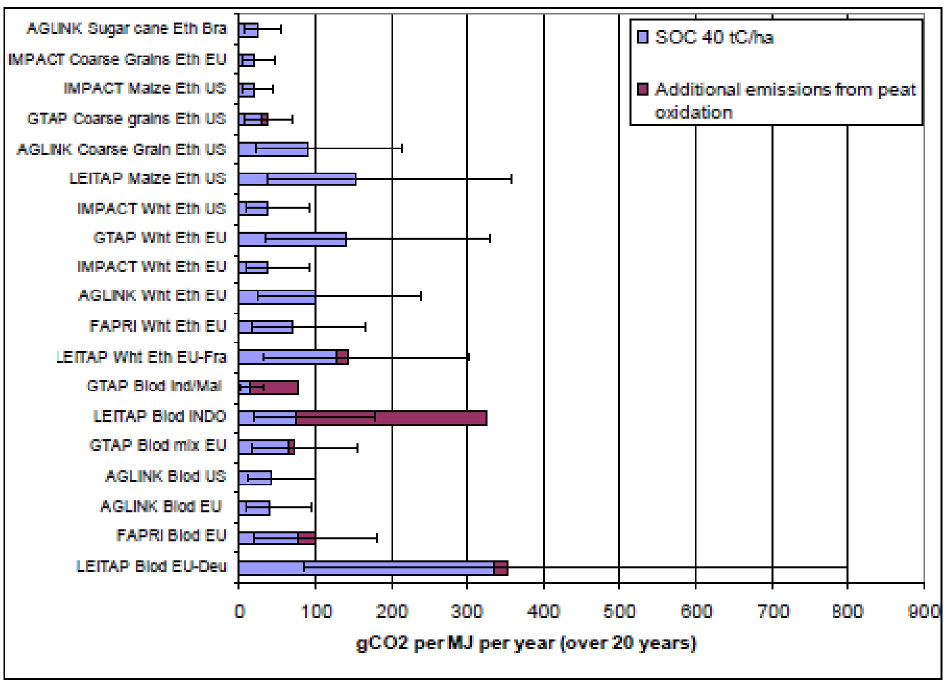


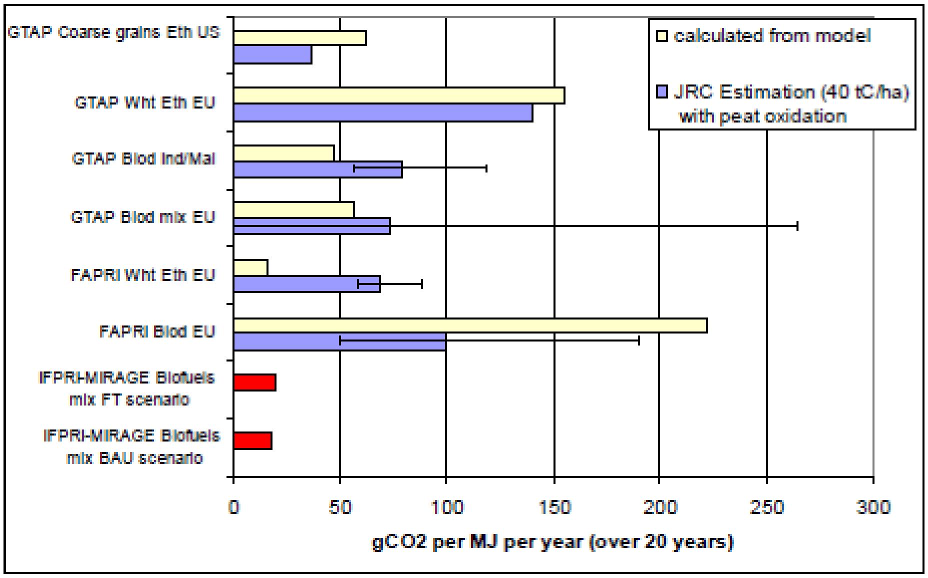
All models show significant LUC in all biofuels scenarios. LEITAP generally shows the highest LUC per toe biofuel. For ethanol scenarios this can be explained by underestimation of the by-products effects, but for EU biodiesel, this explanation is insufficient to account for the large difference. The lowest LUC/toe is shown by the IFPRI-MIRAGE (for DG-TRADE, with a mixed scenario consisting principally of sugar-cane ethanol and rapeseed biodiesel) and IFPRI-IMPACT models. If we take into account that the IFPRI-IMPACT model reported here has no correction for by-products, the results are similar for all IFPRI models. The IFPRI-IMPACT model projects greater yield improvements than the non-IFPRI models. We did not fully analyze the IFPRI-MIRAGE results, but it looks like this model also has a much larger fraction of extra production coming from extra yield than other models, and this requires relatively large quantities of extra fertilizer. It would be interesting to estimate the extra emissions from those extra fertilizers. FAPRI EU-wheat ethanol results involve an increase in meat from ranching which could have significant LUC impact.

Overall results in approximate GHG emissions per MJ biofuels

Here we roughly estimated the range of GHG emissions which one could expect to correspond to the areas of LUC reported by all the models. The central carbon stock change is 40 tC/ha (IPCC default values report 38 to 95 tC/ha for conversion to cropland in EU and North America). The error bars represent the maximum range using 95 tC/ha (value also used in Searchinger et al, 2008), and the minimum derived from the lowest carbon stock change we came across: 10 tC/ha for abandoned EU cropland according to GreenAgSim.

Actual results from the two models who reported LUC emissions are compared with the JRC ranges in the second chart below. We argue that GreenAgSIM currently underestimates emissions for the FAPRI-CARD results for EU wheat.





Emissions from peat oxidation

All models except IFPRI-MIRAGE ignore emissions from the oxidation of tropical peat caused by drainage of tropical peat for planting oil palms. Even with a conservative estimate of emissions from peat oxidation (19 tCO2/y/ha of oil palm, see appendix III), all biodiesel results show significant extra emissions. In the IFPRI-MIRAGE model the emissions per ha of oil-palm are about an order of magnitude too low, because:
- the proportion of *new* oil-palms planted on peat is too low,
- the emissions from peat oxidation consider an IPCC default carbon stock change value which is very low because it does not include the effects of the drainage needed for oil palm, and averages that with a an estimate for the minimum emissions.

Fraction of LUC in EU or US

All models agree that in biodiesel scenarios, most of the land-use change effects occur outside the EU. For EU-wheat bioethanol this is also true, if it is not specified that the feedstock must be *grown* in EU (as in FAPRI-CARD). For US maize ethanol scenarios, all models except LEITAP predict that most of the ILUC effects will be outside US.

Reasons models disagree

The version of LEITAP used had some issues in treating vegetable oils and meals because the oilseeds are not disaggregated into these components. That seems to cause it to underestimate byproduct credits in general, and give anomalous results in the EU biodiesel scenario.

IFPRI-IMPACT has low LUC results because it has the largest contribution from price-induced yield increases, resulting in relatively low area changes even though the model does not consider byproducts. The same thing appears to apply (perhaps even more so) to IFPRI-MIRAGE results for DGTRADE. GTAP apparently has modest contributions from increased yields, but we should bear in mind that part of the price-induced yield increase has been countered by the effect on the average of the considerably lower yield assumed in GTAP for the crop produced on new area. So the effect of *price* on yield may not be much different from that in IFPRI-IMPACT. FAPRI-CARD and AGLINKCOSIMO give relatively modest price impacts on yield. The other factor causing model results to diverge for similar scenarios is the extent to which production is shifted from countries with high yields to relatively less developed countries with lower yields. In our view, for changes over a time period of decades, the models using Armington elasticities probably concentrate crop production too much on the developed world (for biofuel production in the developed world), where yields are higher. The problem is that if one smoothes out annual variations in national market data to find long-term correlations, it becomes impossible to disaggregate these from trends with time. The same problem affects the determination of long-term substitutability between different vegetable oils, or between different cereals: long-term data is almost impossible to separate out, and so short term data tends to be used instead, even though we know this underestimates substitution elasticity. This becomes important if peat land oxidation from palm oil is included in biodiesel emissions: models tend to show rather modest impacts if rapeseed biodiesel on palm oil production, even though long-term trends suggest it is the world's main marginal source of vegetable oil.

The FAPRI-CARD scenario for EU-wheat ethanol gives deceptively low crop area changes because the ethanol-induced shortage of feed-cereals in EU results in meat imports from grazing land rather than cereals imports. By contrast the FAPRI-CARD EU rapeseed biodiesel scenario gives high LUC because it predicts a surprisingly large rapeseed area increase in India, where yields are comparatively low. By coincidence, these differences are further exaggerated by assumptions in the GreenAgSim model for the accompanying emissions.

Models Crop displacements within a region are mostly ignored, underestimating LUC

All models except GTAP assume that the area of cropland expansion depends on the yield of a particular crop whose production increases, whereas in fact it depends on the yield of the crops at the frontier of cultivation. These are typically significantly lower than the yields for the feedstocks (maize, wheat and rapeseed) assumed in these scenarios. (For oilseeds, one should compare cereals equivalent yields here). For EU the yield of crops on the marginal crop area is much lower than considered in any of the models, leading to a large underestimation in LUC area.

Partial Equilibrium vs. general equilibrium models and sensitivities

General equilibrium models attempt to model the whole world economy, whilst partial equilibrium ones stick to the most important aspects affecting agricultural markets. Neither type of model gives consistently higher or lower results. General-equilibrium models appear very sensitive the choice of yield elasticities. All models are sensitive to the **ratio** of yield to area elasticity in different countries, and this ratio is more easily calibrated against historical data than the individual elasticities. The partial equilibrium models would be improved by a proper consideration of crop displacements within regions.

Yield increases on price

Farmers will hardly increase yields beyond baseline unless they see or expect a crop price increase. We distinguish two effects:

- A reversible increase in yield due to price increase. This is taken into account by all models, although they disagree about the size of the effect because of scatter and disagreements about interpretation of econometric data
- An irreversible price-driven increase in the *rate of increase* of yield (so-called "research spending effect"). We show that this can at most have a moderate effect on increasing the elasticity of yield on price.

Indirect Land use change emissions are only part of indirect emissions.

Indirect emissions are the difference between the overall emissions due to making biofuels and the "direct" emissions considered in RE directive default values, which reflect the present emissions from farming on the existing area. Apart from the emissions due to indirect land use change addressed by these models, these include the extra emissions per ton from farming crops on the new land compared to the existing area, and the extra emissions per ton of crops produced by intensification on the existing area.

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