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Impact of energy prices and cellulosic biomass supply on agriculture, energy, and the environment: An integrated modeling approach

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ABSTRACT

The accelerated growth in biofuel markets has both created and reinforced linkages between agriculture and energy. The evolution of biofuel markets over the next 10–20 years and the implications for energy, agriculture, and the environment are uncertain. Building on an integrated agriculture–energy modeling framework, this study analyzes a baseline and three alternative scenarios: two scenarios based on energy prices (crude oil and natural gas) and one based on assumptions regarding cellulosic biomass availability. By examining the impact of scenarios driven by (a) changes in the energy sector and (b) changes in the agricultural sector, we can compare the differential effects on biofuels markets, commodity prices and quantities in each sector, and CO_2 emissions. Scenario comparisons show biofuel markets affected more by crude oil prices than natural gas prices. However, higher natural gas prices shift the biofuel production mix away from corn-grain based to more cellulosic ethanol via multiple mechanisms. Alternatively, the scenario with no cellulosic feedstock lowers total ethanol production and raises ethanol and corn prices. In terms of environmental impacts, higher ethanol levels driven by higher oil prices lead to lower CO_2 emissions. In comparison, the no cellulosic scenario results in the highest CO_2 trajectory relative to the baseline.

1. Introduction

The development of biofuels in the last decade has been driven by government policies aimed at providing domestic energy security, rural economic growth, implied greenhouse gas benefits, and reduced fuel prices. The accelerated growth in biofuels markets has both created and reinforced linkages between agricultural and energy markets. Energy market dynamics, particularly changes in crude oil and natural gas prices, have long affected the profitability of agricultural production. In the past, these changes would affect the cost of producing and transporting agricultural commodities. Since the expansion of biofuels, an added linkage is that energy prices are directly influencing the demand for crops used for biofuel production. Rising energy prices create more demand for the agricultural feedstocks to produce biofuels (Tokgoz et al., 2008). Conversely, the supply of biofuels in energy markets has impacted both the prices (particularly gasoline and diesel) and the quantity of fossil fuels (Hochman et al., 2010). The linkage between energy and agriculture has therefore tightened with the introduction of biofuels.

While there is recognition of the need to examine the impacts of biofuel policies on agricultural markets (Tokgoz et al., 2008) and on energy systems (Rajagopal et al., 2011; Thompson et al., 2011), studies have typically considered these impacts separately. However, for effective policymaking, it is crucial to understand the full implications of biofuels on both agricultural and energy markets through an integrated agriculture–energy market framework (Dodder et al., 2011). Biofuel policies have emerged and changed substantially over the last decade, making estimation of past trends using time series and linear causality methods difficult. The evolution of biofuel technologies, feedstock markets, fuel prices, energy policies, and demand over the next decade and beyond is also uncertain, pointing to the potential utility of examining alternative scenarios using structural models of these two markets.

Elobeid et al. (2013) provide a description of an integrated modeling framework designed to analyze the role of biomass feedstocks from

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agricultural lands and the linkages between biofuel markets and the broader energy sector.[1] The framework includes Iowa State University's Center for Agricultural and Rural Development (CARD) U.S. agricultural markets model and the U.S. Environmental Protection Agency's (EPA) MARKet ALlocation (MARKAL) energy systems model and database. This study builds on the integrated modeling framework of Elobeid et al. (2013) to analyze (a) the impact of energy prices (crude oil and natural gas) and (b) the impact of cellulosic biomass availability on both the agricultural and energy sectors. By examining the impact of scenarios driven by changes in the energy sector and by changes in the agricultural sector, we are able to compare the differential effects on biofuels markets, prices, and quantities in each sector including the effect on CO_2 emissions. Specifically, three scenarios are analyzed: a 25% increase in the U.S. price of crude oil (Scenario 1), a 25% increase in both the U.S. price of crude oil, and the U.S. price of natural gas (Scenario 2), and a scenario where cellulosic biomass feedstock is unavailable to produce advanced cellulosic biofuels (Scenario 3).

The following section explores the agriculture–energy linkages particularly as these linkages pertain to agricultural and energy prices. Then, Section 1.2 addresses the interaction between crude oil and natural gas prices given that one of the scenarios involves analyzing the price increase in both crude oil and natural gas. Finally, to motivate the scenario of no cellulosic biofuel production and the interest in evaluating greenhouse gas (GHG) emissions for all scenarios, Section 1.3 gives a background on the Renewable Fuel Standard (RFS) and the development of cellulosic biomass markets.

1.1. Overview of agricultural-energy linkages

As the linkages between energy and agriculture have tightened, novel interactions between various commodities, sectors, and fuels have emerged. Fig. 1 presents the interactions resulting from the integration of agricultural and energy markets. The agricultural sector, which has historically supplied food as well as feed for livestock and has been a major exporting sector for the U.S., is now also supplying biofuels for transportation purposes. However, agricultural cropland is limited, creating additional competition between the production of food, feed, and fuel. Additionally, the expansion of biofuels, especially ethanol, has created competition with traditional fuels to meet the end-use transportation demand. The biofuels sector (highlighted in green) has therefore added a new layer to the agriculture–energy nexus.

The sharp increase in agricultural prices in recent years has triggered interest among researchers in search of the underlying causes. In addition to rising global demand from an increasing population and rapid economic growth, the rise in energy prices is thought to be a main contributor to agricultural crop prices through two potential means of transmission. The first method of transmission is via the direct impact of higher energy prices on the prices of agricultural commodities. Because agriculture entails an energy-intensive production process, it has been argued that higher crude oil prices result in higher agricultural commodity prices by directly impacting the cost of production. Additionally, higher oil prices increase demand for biofuels, in turn increasing the demand for agricultural commodities and raising the prices of these commodities. The second method of transmission is an indirect impact of energy prices on commodity prices through the exchange rate via its impact on current account deficit or surplus.

These sets of emerging and in some cases strengthening interactions have generated an extensive literature that utilizes various methodologies.

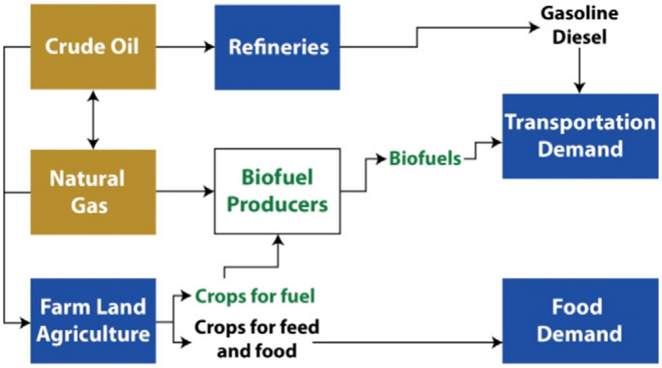

Fig. 1. Agriculture–energy interactions, with biofuel linkages highlighted in green.

One set of analyses relies on time series econometric techniques to quantify the relationship between oil, ethanol, and food prices in levels or interactions in price volatility. Serra and Zilberman (2013) and Gardebroek and Hernandez (2013) provide detailed literature reviews on this issue. Frank and Garcia (2010) break down the relative significance of the relationship between oil and commodity prices and the exchange rate by periods and find that exchange rates and crude oil prices have had limited effects on agricultural markets between 1998 and 2006. However, from 2006 to 2009, the effects become more pronounced, especially in the corn market. Nazlioglu and Soytas (2012), also accounting for the exchange rate, provide evidence that commodity prices are sensitive to changes in crude oil prices and the strength of the U.S. dollar.

There has recently been a movement away from additive frameworks and linear causality methods, which has favored the hypothesis that the prices of the agricultural and energy sectors impact each other. Nazlioglu (2011) tested this hypothesis by using both linear causality and non-parametric causality methods and found that the latter supports the hypothesis of a significant relationship between two prices, while the former does not.

Overall, the link between energy and agricultural commodity prices has proven difficult to estimate econometrically, and the literature has formed two conflicting hypotheses regarding the existence of this link. While the results have been highly dependent on the modeling technique, recent evidence has been in favor of the link between the two sectors based on the inclusion of the exchange rate and the movement away from time series as well as linear causality methods.

1.2. Interaction between crude oil and natural gas

Because one of the scenarios we consider involves analyzing the increase in both crude oil and natural gas prices, addressing the interaction between them is prudent (highlighted in Fig. 1). Crude oil and natural gas are both inputs to the agriculture and energy sectors. Crude oil is an input for gasoline and diesel production, and its price thus affects the transportation costs for agricultural commodities and on-farm operations. Natural gas is an input to agriculture as fuel for on-farm irrigation equipment, chemical feedstock and fuel for fertilizer production, and fuel for pesticide production, crop drying, and biofuel production.

The main drivers of natural gas prices are not fully understood. It has long been established that crude oil and natural gas prices are coupled, although prices seem to diverge from each other at times. Studies such as Brown and Yucel (2008), Bencivenga et al. (2010), and Ramberg and Parsons (2012) have looked at this relationship. These studies attribute the volatility in natural gas prices mainly to seasonal changes, changes in number of heating/cooling degree days, storage levels, and natural gas production shut-downs. Most of the literature has focused on demand fluctuations between the seasons. Ramberg and Parsons (2012) conclude that due to volatility in the natural gas market, today's natural

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[1] Elobeid et al. (2013) also discuss the motivation for using an integrated modeling framework to provide more accurate results by facilitating feedbacks between different sectors. For additional discussion and examples on the use of integrated models, see Kretschmer and Peterson (2010) on the benefits of integrating CGE and PE models; Janssen et al. (2011) on integrated assessment and modeling; and Stoorvogel et al. (2004) on linking econometric simulation models to bio-physical simulation models.

gas prices and the relationship between crude oil and natural gas may not be an indicator for future prices and relationships, although the authors are highly doubtful that the prices will decouple completely and permanently.

Villar and Joutz (2006) and Brown and Yucel (2008) also discuss the integration of crude oil and natural gas markets. Villar and Joutz (2006) apply both cointegration techniques and vector-error correction models to the data from 1989 through 2005 to analyze the relationship between the Henry Hub natural gas price and the West Texas Intermediate crude oil price. The study finds that there have been periods where the prices have seemed to be independent, and after 2000, those periods become more frequent. However, statistically speaking, Villar and Joutz's evidence is in support of a stable relationship between crude oil and natural gas in which the two prices co-move. Brown and Yucel (2008) also analyze the Henry Hub natural gas price and the West Texas Intermediate crude oil price and control for natural gas market factors, such as storage and seasonality. By doing so, the authors find a clear relationship between the two prices and conclude that the crude oil and natural gas markets are cointegrated. Erdős (2012) tests for cointegration using the same vector error correlation estimation as used by Brown and Yucel (2008), but with more recent data. He is able to subsample the data to find that U.S. crude oil and natural gas prices decoupled around 2009, primarily because the increased production of unconventional gas lowered natural gas prices.

1.3. Development of cellulosic biomass markets

The Energy Independence and Security Act (EISA) 2007 was designed with a goal of making the nation less dependent on imported oil for transportation fuels (US EPA, 2010). The Renewable Fuel Standard 2 (RFS2) mandated a goal of 36 billion gallons per year (bgy) of biofuel production for the period 2008 through 2022 of which 16 bgy were expected to come from cellulosic sources, and an additional 5 bgy from other advanced biofuels (biomass diesel and noncellulosic biofuels). Until now, only the corn-based ethanol portion of the standard has been met, and cellulosic biofuel levels have not come close to the originally anticipated levels. In 2013, the U.S. EPA proposed to lower the cellulosic biofuel mandates starting in 2014 due to lack of infrastructure to access biomass, commercialization of cellulosic conversion technologies, blending wall issues, and slow market penetration of flex-fuel vehicles (US EPA, 2013). In addition to energy security, the energy and policy communities anticipated that biofuels, specifically cellulosic biofuels, would provide substantial greenhouse gas (GHG) reduction benefits. While the overall contribution of corn ethanol to GHG reduction goals is unclear (Schnoor, 2011), cellulosic biofuels promise greater reductions in GHG emissions. Thus, in the long run, the unavailability of cellulosic biomass would likely impact the potential for GHG reductions.

Given these new and tightened agriculture–energy linkages, the goal of this study is to investigate the dynamics in the agricultural and biofuel markets under alternative scenarios, which are driven by changes in energy markets on the one hand and agricultural markets on the other hand. The analysis explicitly takes into account the interactions between biofuels, crude oil, natural gas, and corn prices. The simulations investigate three scenarios using the integrated modeling framework previously developed to characterize and quantify the dynamic linkages between the energy system (using the MARKAL model) and agricultural markets (using the CARD model) (Elobeid et al., 2013). The integrated modeling framework allows us to fully explore both the direct and the indirect interactions between energy and agricultural markets and the comparative impact of shifts in the agriculture market versus the energy market for selected scenarios.

The paper asks the following questions. What is the long-term response of biofuel markets to scenario drivers originating in the energy sector, on the one hand, and scenario drivers occurring in the agricultural sector, one the other hand? Is there a differential impact on energy system-wide CO_2 emissions? Using our integrated modeling framework, we define scenarios from both sides of the equation—agriculture and energy. The objective is to examine the relative impacts of scenario drivers that would originate in the energy sector (crude oil and natural gas price changes) versus scenarios driven by changes in the agricultural sector (no cellulosic feedstock for ethanol).

The rest of the paper is organized as follows: Section 2 describes CARD's U.S. agricultural model, EPA's MARKAL energy model, and MARKAL-CARD integration, and the three scenarios implemented. Section 3 presents and discusses the integrated scenario results. Finally, Section 4 outlines the main conclusions and future research directions.

2. Methods

2.1. Integrated MARKAL-CARD modeling framework

The MARKAL model is an engineering-economic optimization model that tracks the evolution of a specific energy system over time for a specific geographic region (Loulou et al., 2004). The EPA's U.S. nine-region database (EPAUS9r_12, version 1.0) is used for the MARKAL input data. Data for EPAUS9r are derived primarily from the Energy Information Administration's (EIA) National Energy Modeling System (NEMS) and results are calibrated to the 2012 Annual Energy Outlook (EIA, 2012). The EPAUS9r database (as well as the national version of the database, represented as a single region) are publicly available and have been used by a number of external users for analysis (see Lenox et al. (2013) for database documentation). Akhtar et al. (2013), Brown et al. (2013), and Yeh et al. (2008) provide examples of analyses using the EPAUS9r database (as well as modified versions) and additional details regarding the database structure. Sarica and Tyner (2013) use a modified EPA MARKAL national database and incorporate land use from the GTAP model so that land rent becomes part of the cost of producing biomass.[2]

The EPAUS9r MARKAL database includes end-use demands for energy services (e.g., vehicle miles of travel, lumens of lighting) and supply curves for coal, natural gas, crude oil, biomass feedstocks (corn stover supply curves based on regional CARD corn production levels), and other non-biomass renewable resources. All resources and technologies are specified for the nine Census Divisions, including costs and energy use associated with transport and transmissions of fuels and electricity. Energy technologies (e.g., light-duty vehicles (LDVs), electric power plants, ethanol refineries) are specified based on their cost (e.g., capital, variable, and fixed operation and maintenance (O&M)) and performance (e.g., capacity, efficiency, and availability). For all energy technologies, the database tracks the combustion-related emissions in the energy sector including carbon dioxide (CO_2), methane (CH_4), nitrogen oxides (NO_x), sulfur dioxide (SO_2), particulate matter (PM), carbon monoxide (CO), and mercury (Hg). MARKAL then solves for the optimal mix of energy technologies and fuels, solving for the lowest system-wide cost, while still meeting additional constraints such as air quality regulations and vehicle efficiency standards.

The CARD U.S. agricultural market model is a non-spatial, partial-equilibrium model that includes major agricultural commodities (temperate crops, sugar, dairy, livestock, and biofuels with by-products). More details on the CARD modeling system can be found in Elobeid et al. (2013), Fabiosa et al. (2010), Tokgoz et al. (2008). There are behavioral equations for crop-planted acreage, domestic food, animal feed, and industrial uses, such as biofuels production, trade, and stocks. The U.S. agricultural market model is part of a broad modeling system of the international agricultural markets, where major agricultural commodity producers such as U.S. and Brazil are represented as separate

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[2] Their analysis differs from this current effort in that they used the national version of the MARKAL database, energy prices are not fed back dynamically as inputs to the cost of production of different crops (e.g., on-farm fuel, fertilizer), and a different set of scenarios are analyzed.

country models. The CARD U.S. model is calibrated on the latest historical data from various sources on supply, utilization, and prices such as the U.S. Department of Agriculture's National Agricultural Statistics Service Database (USDA-NASS, 2011), the World Agricultural Supply and Demand Estimates (USDA-WAOB, 2011), and the U.S. Energy Information Administration (EIA, 2013a). CARD generates annual 10–15-year projections for agricultural commodity supply, utilization, and prices.

Linking these two models to generate an integrated or “converged” baseline and then using this baseline to run various scenarios allows for detailed analysis of the impacts of energy markets on agricultural markets and vice versa. This linkage takes advantage of the relative strengths and high level of detail of each model for their respective markets as they relate to biofuels. On the demand side, the MARKAL model includes a high level of technological detail for the LDV fleet (including penetration of ethanol compatible flex-fuel vehicles (FFVs)), as well as regional production and distribution of fuels, and represents interactions between all sectors of the energy system, including the transportation, residential, commercial, and industrial demand sectors, as well as the electric power sector and refineries. On the supply side, the CARD model includes harvested area for the major crops by region and state. Additionally, the CARD model includes all co-products and by-products resulting from the processing of these crops. For example, for corn, the model includes behavioral equations for corn gluten meal, corn gluten feed, high fructose corn syrup, ethanol, etc. Soybean meal, soybean oil, and biodiesel are also modeled for the soybean sector. The model allows for the interaction of the different sectors and solves for equilibrium prices that equate supply and demand in all markets.

When modeling biofuels production volumes, the MARKAL energy system model considers certain agricultural variables, such as corn prices, as exogenous. Similarly, the CARD model takes energy prices, such as gasoline or natural gas prices, as exogenous. Such variables become endogenous in an integrated modeling framework. The integrated MARKAL-CARD framework outlined in detail in Elobeid et al. (2013) defines: (a) variables that could be exchanged by iteratively running the two models; (b) static variables that could be harmonized across models; and (c) criteria that determine convergence between the two models. Sensitivity analyses were run to identify those parameters that most affected the individual model results with respect to biofuels, and those parameters were then prioritized for inclusion in the data exchanges between the two models. Fig. 2 highlights the key dynamic variables that are exchanged from one model to another, as well as harmonized parameters that do not vary between runs.

2.2. Baseline and Scenarios

Elobeid et al (2013) describe in detail the steps involved in both generating the baseline and running scenarios using the integrated MARKAL-CARD modeling framework. The main steps are as follows: (i) harmonization of modeling inputs (updated historical data) and assumptions (e.g., regarding technology and policy); (ii) identification of variables to be included in data exchanges; (iii) generation of the integrated baseline by running the two models iteratively until they converge on corn ethanol production volumes; (iv) running scenarios using the integrated modeling framework. Running the CARD and MARKAL models independently tends to overestimate the responses to shocks because there are no feedback effects, which can have significant policy implications. Linking the models endogenizes the interaction between two markets and better reflects real-world market dynamics, where all markets interact with each other (additional details on running two-way model linkages for convergence is in the Supplementary Material).

In this analysis, EISA 2007 *advanced* fuel mandates (US EPA, 2010) are not imposed in the baseline or scenarios, because including the volumetric constraints as lower production limits would allow little flexibility in the response of the MARKAL model in terms of changes in cellulosic ethanol production. In addition, only corn stover feedstocks are included for cellulosic ethanol production, whereas the EISA 2007 includes a broader range of potential feedstocks. From a modeling perspective, to gain insights regarding the response of biofuels production to changes in fuel prices, a fixed minimum volume for the advanced fuel mandates would possibly hold advanced fuel volumes artificially high under some price scenarios. For corn-ethanol and biodiesel consumption, the EISA mandate is assumed to be met. These results should therefore be considered alternative scenarios, as opposed to projections. The goal is not to predict, but rather to understand the relative magnitude of the impact of crude oil and natural gas prices on biofuels markets, accounting for the complex set of energy–agriculture linkages as illustrated conceptually in Fig. 1 and as modeled according to Fig. 2.

The two scenarios identified to analyze the impacts of changing fossil fuel prices on biofuels and agricultural markets are: (1) a permanent

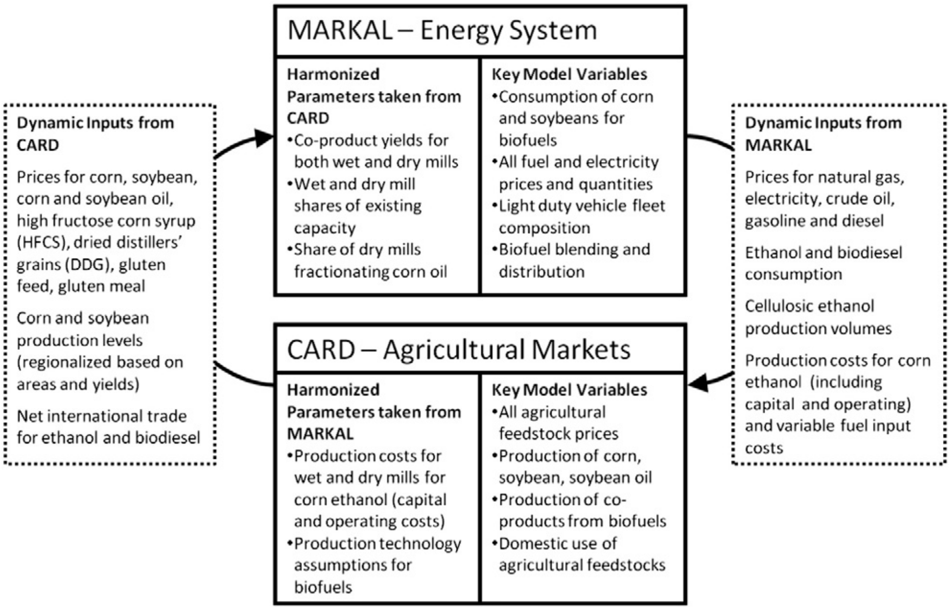

Fig. 2. Integrated MARKAL-CARD modeling framework.

Table 1
Integrated results for fuel/feedstock consumption: baseline versus scenarios for 2025.

		Baseline	Scenario 1: Crude oil price		Scenario 2: Crude oil plus natural gas prices		Scenario 3: No cellulosic markets	
				% Change		% Change		% Change
Fuel use by light duty vehicle type[a]								
E85 or gas/E10 in FFVs[b]	PJ	2127	2572	21.0	2585	21.6	1898	−10.7
Gas/E10 (ICE or hybrid)[c]	PJ	12,618	12,169	−3.6	12,155	−3.7	12,848	1.8
CNG vehicles	PJ	2	2	0.0	2	0.0	2	0.0
Electricity (PHEV/EV)[d]	PJ	0	0	0.0	0	0.0	0	0.0
LPG	PJ	5	5	0.0	5	0.0	5	0.0
Diesel	PJ	478	479	0.1	479	0.1	478	0.0
Total fuel use	PJ	15,230	15,227	0.0	15,227	0.0	15,232	0.0
Domestic consumption								
E10	M gal	105,602	103,332	−2.1	103,210	−2.3	107,495	1.8
Ethanol in E10	M gal	10,560	10,333	−2.1	10,321	−2.3	10,749	1.8
E85	M gal	17,625	22,278	26.4	22,423	27.2	15,146	−14.1
Ethanol in E85	M gal	14,982	18,936	26.4	19,059	27.2	12,874	−14.1
Reformulated gasoline	M gal	105,780	103,293	−2.4	103,217	−2.4	107,062	1.2
Total ethanol blended	M gal	25,542	29,269	14.6	29,380	15.0	23,624	−7.5
Crude oil use	M bbl	4551	4473	−1.7	4472	−1.7	4579	0.6
Natural gas use	Tcf	25.1	25.1	0.3	24.4	−3.0	25.2	0.2
Change in refinery outputs								
Gasoline output	M gal	97,219	94,269	−3.0	94,191	−3.1	98,527	1.3
Diesel output	M gal	60,318	60,250	−0.1	60,278	−0.1	60,221	−0.2
Feedstock consumption								
Corn for ethanol	M bu	5873	6966	18.6	6924	17.9	6954	18.4
Cellulosic feedstocks	M ton	63.6	69.7	9.5	72.6	14.1	3.1	−95.1

[a] In MARKAL, end-use vehicle efficiency and fuel use is defined in units of energy, not volumes. PJ are also used here for direct comparison of energy use for different liquid fuels and electricity. For all other variables figures are presented in volumes or mass.

[b] Flex Fuel Vehicles (FFVs) using either E85 or gasoline/E10.

[c] Conventional Internal Combustion Engine (ICE) or Plug-In Hybrid Electric Vehicle (PHEV) using gasoline/E10.

[d] Electric Vehicles (EV) are battery only.

25% increase in crude oil prices; and (2) a permanent 25% increase in both crude oil and natural gas prices. Crude oil prices will primarily impact biofuels demand whereas natural gas prices will primarily impact the cost of production of crops and the cost of production of dry-mill natural gas fired ethanol facilities. We hypothesize that the crude oil price changes will have a stronger net effect on biofuels markets and feedstocks, as both a direct competitor in the transportation fuels market and an input, than natural gas prices, which only affect input costs.

The first scenario is designed to test the sensitivity of the biofuels markets to changes in the prices for domestic and imported crude oil. In addition, this scenario somewhat simulates a decoupling situation between the two fossil fuel markets as the price of natural gas stays the same while crude oil prices are increasing. The crude oil prices, which are defined through supply curves in MARKAL, are shifted 25% upwards, and the resultant price index is passed onto the CARD model.

The second scenario is a combined scenario of both higher crude oil and higher natural gas prices. In this case, integrated oil and gas markets are assumed, and the prices for crude oil and natural gas increase simultaneously. Similarly, the MARKAL supply curves that define the price and quantity relationship for crude oil and natural gas are shifted upwards to simulate a 25% price increase. The resultant diesel, gasoline, and natural gas price indices are passed on to the CARD model.

While the first two scenario drivers originate in the energy sector, we also assess changes driven by the agricultural sector. Thus, a third scenario analyzes the impact of unavailability of cellulosic biomass feedstock (in particular, corn stover) for ethanol production on the biofuels, energy, and agricultural markets. The absence of cellulosic biomass for bioenergy production means that only corn-based ethanol can be used to meet the demand for biofuels and creates upward pressure on the price of corn. Without cellulosic biofuels and at higher corn prices, we hypothesize a lower total biofuels production volume. With the scenario's drivers coming from both sides of the energy–agriculture linkage, this scenario sheds light on how the removal of cellulosic feedstock affects fuels and other commodity prices and volumes.

3. Results and discussion

The MARKAL-CARD integrated framework is utilized to implement baseline future conditions and three additional scenarios as described in the previous section.[3] The results are expressed in terms of the percent difference between the scenario and the baseline. For the integrated model results, we first discuss the end results for changes in the broader energy system and end-use fuel consumption (Section 3.1), the impacts on biofuel production levels and mix (Section 3.2), then relative energy-system wide and transportation CO_2 emissions among scenarios (Section 3.3), and finally, the impacts on agricultural markets (Section 3.4).

3.1. Changes in the energy system

Because the first two scenarios are driven by the increased energy prices, MARKAL is used to implement the price increases for crude oil and for both crude oil and natural gas simultaneously. These higher prices translate into higher prices for gasoline, diesel, and other refinery products relative to the baseline. Higher prices depress demand for fuels such as gasoline and increase the relative competitiveness of ethanol. These results are passed back to the CARD model, essentially moving from top to bottom via the data exchanges identified in the right-hand box in Fig. 2.

Table 1 highlights key energy system changes for the year 2025 for the integrated modeling results. The major shifts in the end-use demand for fuels by LDVs highlight the competition between ethanol and gasoline blends, in particular, with much higher levels of E85 blends. In the first scenario, total ethanol consumed (including all

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[3] We also look at the impact of the two energy price scenarios when implemented in the CARD and MARKAL models separately with no feedback between the models. This further expands and corroborates the findings in Elobeid et al. (2013). The results and discussion of this effort are summarized in the Supplementary Material.

corn, cellulosic and imported ethanol) increases by 14.6%. Little change occurs in other end-use fuels in the LDV sector. However, the shifts in ethanol versus gasoline affect refinery production levels and mix, with a drop of 1.7% in total crude oil consumption, as well as changes in the mix of refined products toward a greater share of diesel, which meets the heavy duty vehicle demand. Refinery diesel output decreases only 0.1% relative to a 3.1% decrease in gasoline output. For the second scenario, the 25% price increases lead to a 3.0% net decrease in total natural gas consumption. Natural gas use decreases primarily in electric power generation and secondarily in the industrial and commercial sectors. In contrast, residential consumption of natural gas actually increases. As high natural gas prices increase electricity prices, and heating oil prices are high because of the high crude prices, direct use of natural gas in residential space heating and cooking become relatively more cost effective than either heating oil or electricity.

For the third scenario, total ethanol consumed decreases by 7.5% by 2025. Compared to the baseline and first two scenarios, small changes (−0.6%) are seen in crude oil consumption as well as the refineries' gasoline output (1.3%). The largest impact of the unavailability of cellulosic biomass is the reduction in use of E85 by 14.1% in 2025. Limiting ethanol feedstock to corn means that only corn-based ethanol blends can compete with gasoline, resulting in corn prices higher than the baseline. Corn ethanol increases relative to the baseline to close the gap in ethanol demand. The net result is lower total ethanol levels with E85 blends dropping substantially. Interestingly, although the direction is different, the magnitude of change in E85 use (down 14.1%) due to no cellulosic markets is roughly half of the change of E85 use (up 27.2%) due to a 25% increase in oil prices. The no cellulosic scenario leads to relatively smaller impact on gasoline and diesel prices, as would be expected compared to the more direct impact of higher crude prices. However, secondary or indirect impacts are seen in the gasoline markets, with higher gasoline and E10 use, and increases (albeit small) in gasoline prices.

Fig. 3 illustrates the changes in key energy quantities (percent change relative to the baseline) that are part of the data exchange from MARKAL to CARD (changes in prices are shown in Supplementary Material). In the first scenario, the 25% higher crude oil price results in price increases of 11–14% for gasoline and 15–16% for diesel, depressing the demand for gasoline/E10 between 2% and 4%. The largest relative fuel price increase occurs in the earlier time periods, whereas prices adjust back closer to the baseline by 2025. The addition of the higher natural gas prices in the second scenario results in similar changes in gasoline and diesel prices, as expected, as well as the similar changes in gasoline volumes. There are more pronounced differences in overall ethanol demand for each of the periods, which in part reflects changes in the relative cost of corn and cellulosic ethanol due to changes in natural gas prices, as discussed earlier. However, gasoline and E85 volume changes are similar under both energy price scenarios. Comparatively, the no cellulosic scenario leads to the opposite results. Albeit to a lesser extent, ethanol and E85 volumes fall in the absence of cellulosic biomass availability due to the drop in total ethanol produced. Gasoline and E10 volumes also respond, with small increases in consumption.

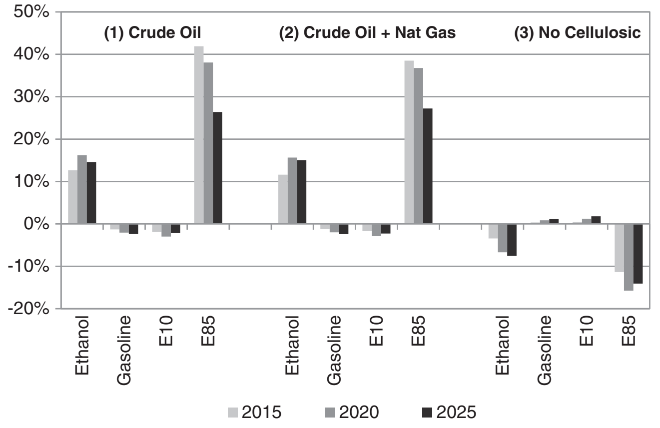

Fig. 3. Volumes of ethanol, gasoline and blends consumed: percent change from the baseline for all scenarios.

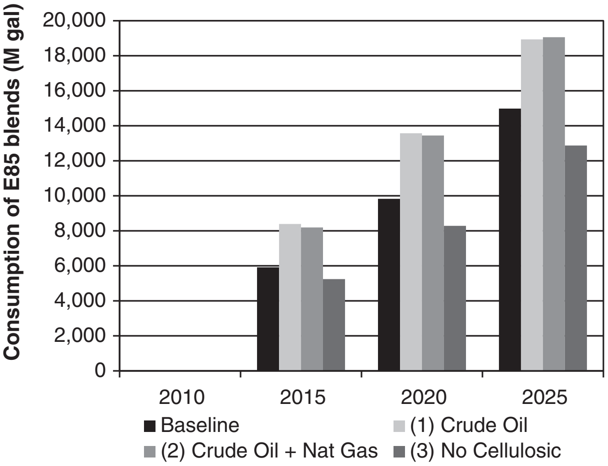

Fig. 4. Volumes of E85 blends for the baseline and three scenarios from 2010 to 2025.

For all scenarios, the largest change relative to the baseline is the E85 consumption. E85 use increases in the first scenario by 42%, 38%, and 26% (in 2015, 2020, and 2025, respectively) above the baseline, by 39%, 37%, and 27%, respectively, above the baseline in the second scenario, and decreases in the third scenario by 11%, 16%, and 14%, respectively (Fig. 3). Gasoline, before blending, decreases 1.2–2.4% below the baseline (Fig. 3), and increases by less than 1% in the third scenario. The high percentage increase in E85 in the earlier years is also in part a function of the lower absolute levels in those years. The volume increases in E85 consumption (shown in Fig. 4) show the upward shift from the baseline for the energy price scenarios, and downward shift from the baseline for the no cellulosic scenario.

Fig. 5 shows the changes in ethanol consumption at the regional level. Nearly all baseline E85 consumption occurs in Midwestern ethanol producing states (regions 3 and 4, corresponding to the East North Central and West North Central Census Divisions). Additional E85 volumes in the scenarios are also absorbed by these same regions. Lower regional prices and high availability of feedstock (as taken from the CARD results) concentrate both corn and cellulosic ethanol production in these states. In addition, the distribution costs (via rail, truck, or barge), as solved endogenously in the MARKAL model, often make it more cost effective at the system-level to consume ethanol close to the feedstock and fuel production. Distribution costs, particularly for truck-based transport of ethanol, are further exacerbated under the two scenarios, which increase the cost of diesel for ethanol transportation. As an optimization model, MARKAL optimizes the regional flows of ethanol production, distribution, and consumption to an extent that would not necessarily occur in the real world. MARKAL also optimizes the geographic location of E85 compatible FFVs, and due to the assumption of perfect foresight in the model, is able to build out the FFV fleet in anticipation of higher ethanol volumes in later modeling years.[4] However, there is in fact a heavy concentration of ethanol blending and FFV use in the Midwest, with 77–82% of high ethanol blends located in the Midwest Petroleum Acquisition Defense District (PADD) II between 2010 and 2012 (EIA, 2013b). In terms of looking ahead to higher E85

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[4] In EPAUS9r, FFVs are relatively indistinguishable from their conventional gasoline vehicles for the same vehicle class size, with similar efficiencies on an energy basis (between 1% and 4% efficiency loss for E85 vehicles depending on vehicle class), and a marginal difference in existing vehicle cost (0.3% higher), but no difference for future years and more advanced vehicles.

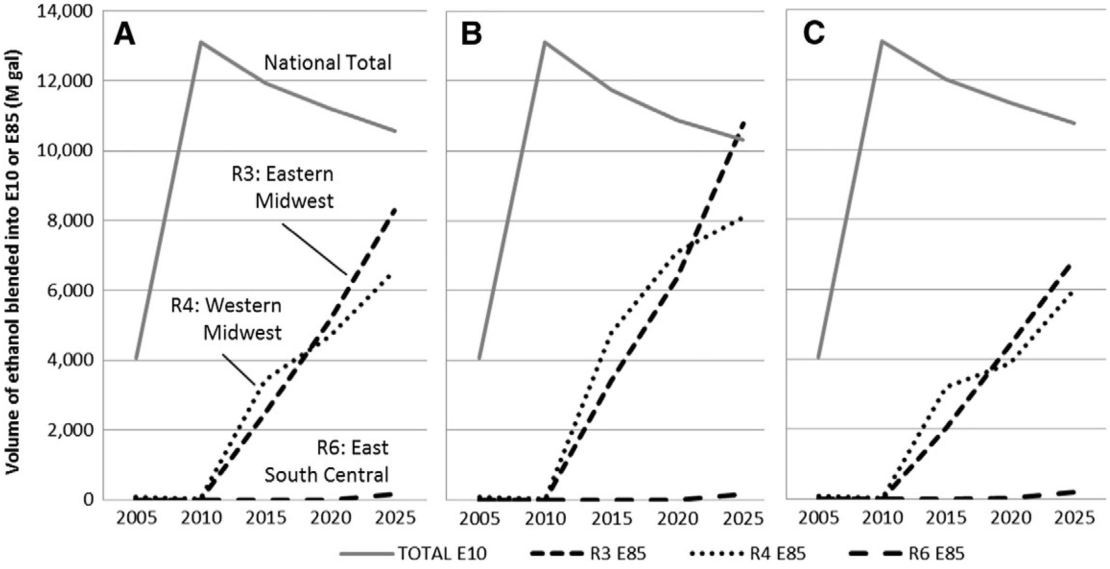

Fig. 5. Growth of denatured ethanol blended into E10 nationally (solid lines) versus E85 regionally (dashed lines). Trends are shown for (A) baseline, (B) scenario 2 (high crude oil and natural gas), and (C) scenario 3 (no cellulosic).

penetration, Wakeley et al. (2009) also looked at an optimized system, highlighting that long-distance transportation erodes the economic (as well as environmental) benefits of ethanol relative to gasoline and recommended regional concentration of E85 blends.

3.2. Impact on production of biofuels

Turning to the changes in production of biofuels, higher consumption of E85 boosts domestic ethanol production by 16.6% in the high crude oil price only scenario (Table 2). This growth comes from both corn-based ethanol, which is 18.7% higher relative to the baseline, and cellulosic ethanol from corn stover, 9.5% higher relative to the baseline. The second scenario yields similar results with respect to total domestic ethanol production levels at 17.1% higher than the baseline. Biodiesel levels and net trade are similar and also change little relative (in absolute terms) to the baseline. In the second scenario, the shift plays out in the relative mix of corn-grain ethanol (18.0% higher), versus cellulosic based ethanol (14.1% higher). Higher natural gas prices increase the cost of production of (and thus lower the demand for) corn-based ethanol via two mechanisms. First, new dry mill corn-grain ethanol capacity is assumed to be natural gas-fired, meaning higher natural gas prices translate into higher energy costs of production. Second, and more importantly, the corn feedstock costs for the dry mills also increase due to higher fertilizer prices, which are tightly correlated to the price of natural gas (GAO, 2003; Kim and Dale, 2008). Cellulosic ethanol production (modeled in MARKAL based on the techno-economic evaluation developed by Humbird et al. (2011), see Supplementary Material) uses the lignin from the cellulosic biomass to provide process heat and electricity, meaning that natural gas is not a required input or cost for cellulosic ethanol production. In the third scenario, due to unavailability of cellulosic feedstocks, total ethanol production decreases by 8.6% with the production of corn ethanol at similar levels as in the other scenarios by 2025. Therefore, with respect to corn ethanol demand and production levels (by 2025), an assumption of no cellulosic markets has a similar effect to assuming 25% higher crude prices.

Fig. 6 shows changes in denatured ethanol volumes over time. The model runs begin with the period 2005–2010 linked to historical production volumes, while 2011 and onward represent model results. All scenarios lead to early expansion of corn ethanol production relative to the baseline. However, only in the later model run years (2020–2025) do the cellulosic production levels begin to diverge from the baseline. As a result, most of the additional ethanol/E85 demand is first met with corn-based ethanol, with cellulosic-based ethanol meeting additional demand only in later periods. Net trade in ethanol and biodiesel changes little between the baseline run and the scenarios, with the increased demand for ethanol met almost entirely by the growth in domestic production of both corn and cellulosic ethanol.[5]

3.3. Changes in energy system-wide CO_2 emissions

Fig. 7 presents the changes in energy system-wide CO_2 emissions among the scenarios. The level of ethanol and gasoline consumption is the main influencer of the CO_2 emissions in the transportation sector (Figure S2 in Supplementary Material). The more ethanol is consumed, the lower are the system-wide CO_2 emissions. The gasoline use is highest in Scenario 3 resulting in the highest CO_2 emissions over the modeling horizon. Compared to the baseline, scenarios 1 and 2 result in lower but similar levels of gasoline and ethanol consumption in the transportation sector. However, the system-wide CO_2 emissions for Scenario 2 are higher than the ones for Scenario 1. The 25% increase in natural gas prices in Scenario 2 results in decreased consumption of natural gas in the power sector. Therefore, the power sector CO_2 emissions are increased with respect to Scenario 1 (Figure S3 in Supplementary Material). Aggregate CO_2 emissions decrease by 0.3% in Scenario 1 with respect to the baseline when ethanol production increases by 16.6% (Table 2).

The results reported here account for the energy-system emissions related to production, conversion, and use of energy. Agricultural management of biomass also may result in carbon sequestration. The framework laid out in Elobeid et al. (2013), which builds on the integrated agricultural and energy markets modeling and links these macro influencers with the micro level dynamics (e.g., farm-level decisions on tilling), could be used to estimate associated carbon sequestration benefits.

3.4. Changes in agricultural markets

Table 3 presents the integrated model results for the agricultural sector under the two energy price scenarios and the no cellulosic feedstock

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[5] Net trade equations in the CARD U.S. agricultural model are reduced form equations that mimic the response of world biofuel markets.

Table 2
Integrated results for biofuel production and trade: baseline versus scenarios for 2025.

	Baseline	Scenario 1: Crude oil price		Scenario 2: Crude oil plus natural gas prices		Scenario 3: No cellulosic markets	
	M gal	M gal	% Change	M gal	% Change	M gal	% Change
Total ethanol production	22,451	26,177	16.6	26,287	17.1	20,527	−8.6
Corn ethanol	17,324	20,562	18.7	20,437	18.0	20,527	18.5
Cellulosic ethanol	5127	5615	9.5	5850	14.1	0	−100
Soybean oil biodiesel	1009	1004	−0.5	1004	−0.5	1006	−0.3
Ethanol net trade[a] **(CY)**[b]	−3091	−3093	0.1	−3093	0.1	−3097	0.2
Biodiesel net trade[a] **(MY)**[b]	16	11	−31.3	10	−37.5	13	−21.3

[a] Net trade is exports minus imports.
[b] CY = Calendar Year, MY = Marketing Year, Sep-Aug

for ethanol scenario for the year 2025/26. For the first scenario, an increase in the price of crude oil by 25% increases the retail price of unleaded gasoline by 10.4%, which makes ethanol relatively cheaper than gasoline as a fuel substitute. The demand for ethanol therefore increases by 15%. Consequently, the corn used in ethanol production goes up by 19%, increasing the price of corn by 4.6%. The increase in ethanol demand induces a 4.5% increase in the price of conventional (corn) ethanol.

The higher corn price increases the area harvested and production of corn by 3.7% and 3.9%, respectively (Table 3). The higher corn production area comes at the expense of areas for competing crops, mostly soybeans and wheat, which decrease by about 2.3% and 0.9%, respectively, for the year 2025/26. The lower supply of these (and other competing) crops increases their respective prices, by 1.3% for soybeans and 2.3% for wheat. Given that corn is now more expensive, the other uses for corn, namely feed and food, decline. Corn exports also decline as do the exports of soybeans and wheat.

The change in crude oil prices does not significantly affect the cost of production for crops, since the price of fertilizer, which is affected more by natural gas prices, changes little with the increase in the crude oil price. Fertilizer makes up over 40% of total cost in the case of corn and wheat (17% in the case of soybeans). Fuel costs, on the other hand, range between 10% and 15% of the total variable cost for most of the major crops.

With the higher soybean prices, use of soybean crush for oil declines by 1.2%, which results in lower soybean oil production (by 1.2%). Lower soybean oil supply increases soybean oil prices by 0.44% and reduces total soybean oil use by 1.7%. Soybean oil used for biodiesel falls by 3.3% and the biodiesel price increases slightly in the year 2025/26.

The results for the second scenario in Table 3 show that the incremental impact of the addition of the higher natural gas price is marginal, i.e., the changes between the baseline and the second scenario are not very different from the changes between the baseline and the first scenario. This small difference between scenarios indicates that the impact of a change in the crude oil price on the agricultural and biofuel market is significantly larger than the impact of a change in the price of natural gas.

Ethanol production and consumption in the second scenario increase by 17% and 15%, respectively, relative to the baseline. These changes are similar to the changes in the first scenario. The major difference between the two scenarios is the impact of the higher natural gas price on the variable cost of production, particularly through the higher prices for two fertilizer products. The variable cost of production increases by 2.7% for corn and by 0.4% for soybeans brought about by an almost 9% increase in the price of nitrogen fertilizer and a 2.3% increase in the price of potash and phosphate. The variable cost of production for soybeans is not affected significantly by the higher natural gas price given that no nitrogen fertilizer is used in soybean production. Consequently, the increase in the corn price, which is higher in the second scenario when compared to the first, reflects not only the higher demand for ethanol but also the higher cost of production resulting from the increased natural gas price.

In the third scenario, corn replaces corn stover in ethanol production, resulting in an increase of 18.5% in corn use for ethanol and 6.3% increase in total domestic use. Thus, corn prices increase by 4.76% relative to baseline, which reflects a higher increase compared to other scenarios. Total ethanol production decreases in this scenario by 8.6% (Table 2) since the increase in corn ethanol production cannot make up for the decrease in cellulosic ethanol production. Higher demand for corn increases corn prices, shifting area away from other crops to corn. This leads to higher prices for all agricultural commodities, for example, 1.4% for soybeans and 0.5% for soybean oil. One interesting result is the impact of no cellulosic ethanol on transportation fuel prices. Despite substitution of corn ethanol, total ethanol availability in the

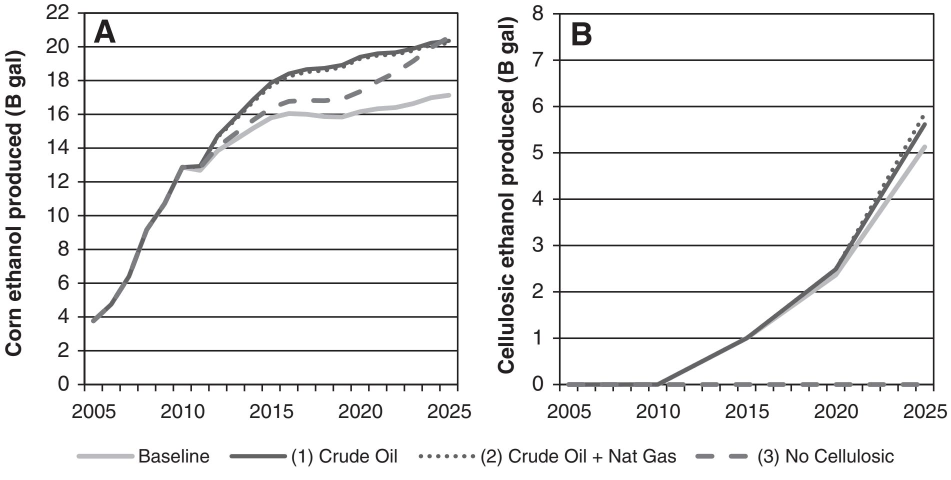

Fig. 6. Denatured ethanol volumes for the baseline and three scenarios from (A) corn-based ethanol production, and (B) cellulosic ethanol production.

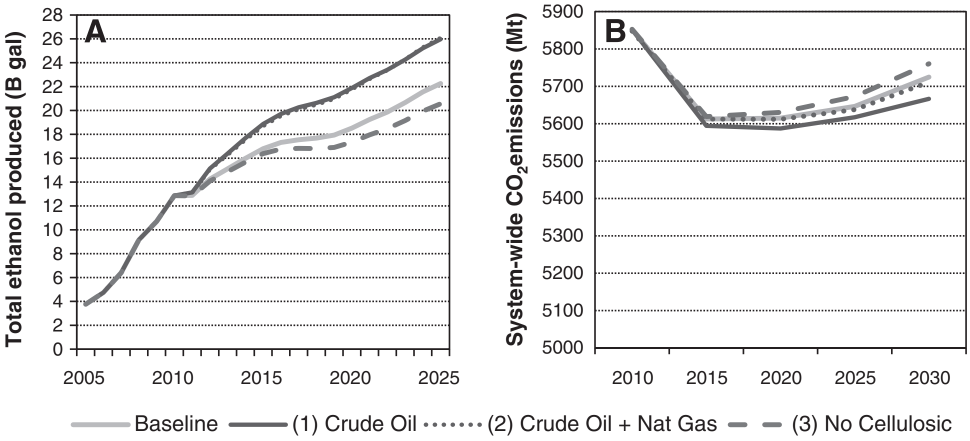

Fig. 7. (A) Total denatured ethanol and (B) system-wide CO_2 emissions for the baseline and three scenarios. The axis for system-wide CO_2 emissions starts at 5000 Mt, due to small relative differences among scenarios.

transportation market declines. This leads to a 0.9% increase in the gasoline price and 0.25% increase in the biodiesel price. This scenario result, combined with the energy price scenario results, show that agriculture and energy systems are well integrated such that a shock in one system has non-negligible impacts on the other system.

4. Conclusions

This work leverages the agriculture–energy modeling framework developed in Elobeid et al. (2013) and provides additional insights by imposing high energy price scenarios and a no-cellulosic scenario in the fully integrated framework (for comparison, the non-integrated model results for the high energy price scenarios are summarized in the Supplementary Material). The results provided by this integrated agriculture–energy modeling framework in the context of biofuels fall along two lines. First, the scenarios highlight the substantial impact of changes in crude oil and natural gas prices on biofuels production and use, as well as a significant response in agricultural markets (i.e. the impact of energy on agriculture). Second, with the no cellulosic scenario, the results demonstrate that while the impacts on the overall energy markets are less pronounced than in scenarios 1 and 2, the impacts on corn-based ethanol demand and corn prices are similar. The no

Table 3
Integrated results for the agricultural sector: baseline versus scenarios for 2025/2026.

		Baseline	Scenario 1: Crude oil price		Scenario 2: Crude oil plus natural gas prices		Scenario 3: No cellulosic ethanol	
				% Change		% Change		% Change
Harvested acres								
Corn	M acres	92.5	95.9	3.66	95.7	3.46	96.0	3.75
Soybeans	M acres	73.5	71.9	−2.27	72.0	−2.16	72	−2.34
Production								
Corn	M bushels	17,581	18,275	3.94	18,229	3.68	18,264	3.89
Soybeans	M bushels	3602	3517	−2.36	3520	−2.26	3511	−2.52
Soybean oil	M pounds	21,997	21,724	−1.24	21,736	−1.19	21,720	−1.26
Total domestic use								
Corn	M bushels	13,622	14,485	6.34	14,442	6.02	14,477	6.27
Ethanol use	M bushels	5889	6986	18.64	6945	17.93	6976	18.46
Soybeans	M bushels	2049	2020	−1.41	2021	−1.35	2019	−1.47
Soybean oil	M pounds	18,292	17,987	−1.66	18,011	−1.53	17,990	−1.65
Biodiesel use	M pounds	2454	2372	−3.34	2368	−3.51	2389	−2.63
Exports								
Corn	M bushels	3927	3757	−4.32	3756	−4.35	3754	−4.42
Soybeans	M bushels	1557	1501	−3.58	1504	−3.44	1497	−3.82
Soybean oil	M pounds	3844	3874	0.79	3862	0.47	3869	0.64
Price								
Corn	$/bushel	4.76	4.98	4.64	4.99	4.74	4.99	4.76
Soybeans	$/bushel	11.07	11.21	1.34	11.21	1.29	11.22	1.39
Soybean oil	cents per pound	54.35	54.60	0.44	54.62	0.48	54.63	0.52
Unleaded gasoline, retail	$/gallon	3.75	4.14	10.42	4.09	9.17	3.78	0.86
Biodiesel	$/gallon	5.10	5.11	0.21	5.11	0.22	5.11	0.25
Ethanol (conventional)	$/gallon	1.92	2.00	4.34	2.03	5.91	2.28	18.64
Variable production expenses								
Corn	$/acre	405.21	405.98	0.19	416.30	2.74	405.90	0.17
Soybeans	$/acre	165.36	165.48	0.07	166.02	0.40	165.49	0.08
Fertilizer prices (calendar year 2025)								
Nitrogen	PPI (90–92 = 100)[a]	399.83	399.85	0.01	434.86	8.76	399.83	0.00
Potash and phosphate	PPI (90–92 = 100)	538.78	541.00	0.41	550.92	2.25	541.23	0.45

Note: There is a difference between percentage changes and the results in values due to rounding. 2025/26 is marketing year, which corresponds to the calendar year 2025.

[a] PPI = Prices Paid Index (1990–1992 = 100).

cellulosic scenario also shows that there is a second order or indirect effect on the energy markets, via small increases in gasoline consumption (i.e. the impact of agriculture on energy).

The results show that the impact of crude oil prices on the demand for biofuels and their feedstocks is much greater than the impact of natural gas prices on the cost of production of corn and biofuels. This is also true in the case of non-feedstock cost of production of dry-mill natural-gas-fired ethanol facilities. As expected, the crude oil prices have a pronounced effect on biofuels markets and overall feedstock demand. Referring back to Fig. 1, the main driver is the interaction between crude oil-based fuels and biofuels. In terms of total ethanol demand, the question of coupled versus non-coupled natural gas and crude oil markets appears to be secondary to the trends in the crude oil markets alone. Both price shocks—crude oil only, and crude oil and natural gas together—in both the linked and unlinked models show relatively similar outcomes in terms of the end-use energy demand from the LDV fleet. The major shift occurs in the increased penetration (between 21% and 22% higher than baseline) of FFVs, geographically concentrated in the ethanol-producing states. However, as the use of E85 increases across scenarios, there are substantial differences in how that demand for additional ethanol is met—via a mix of corn-based ethanol and cellulosic ethanol—where the changes in natural gas prices do have a significant impact. Higher natural gas prices, coupled with high crude oil prices, provide the largest impetus to the cellulosic ethanol markets due to the disadvantage that the higher natural gas prices place on corn-ethanol via the increased fertilizer prices and cost of natural gas for the dry-mill facilities.

On the cellulosic biomass market side, feedstock unavailability decreases total ethanol production and consumption relative to all scenarios, including the baseline. Compared to the baseline, the lack of cellulosic biomass markets results in an additional push to produce more corn ethanol thus increasing corn prices at levels similar to prices in the first and second scenarios.

In terms of CO_2 emissions, the higher ethanol levels (both corn and cellulosic) in the first and second scenario result in lower CO_2 emissions, both due to higher fossil fuel prices (which dampened the use of crude oil and natural gas in other sectors) and due to increased cellulosic volumes. However, the lack of cellulosic biofuels in the third scenario results in an increased system-wide CO_2 trajectory compared to the baseline. Our results indicate an energy system-wide CO_2 reduction benefit from cellulosic biofuels. However, farm-level agricultural carbon accounting measures must be utilized to determine whether overall carbon benefits are positive.

The key outcome of the application of this integrated agriculture–energy modeling framework is highlighting the extent to which crude oil and natural gas prices as well as unavailability of cellulosic feedstocks may affect ethanol demand and its production mix in the future. The forward looking element of the scenarios is critical, because it allows insights related to two key issues: the extent to which the nascent E85 market and FFV fleet will expand over time, and the relative role of corn grain versus cellulosic feedstocks in meeting the demand for renewable fuels, ethanol in this case. These unknowns are critical and lack enough historical data to guide future estimations. Scenarios are therefore an appropriate way to gain insights into potential market interactions and trends.

Furthermore, the two markets may be radically transformed as they move beyond the E10 blend wall and as cellulosic biofuels transition from pilot and demonstration scale into commercial production. Since biofuels market expansions are driven primarily by policies, such as mandates, there are relatively few studies that specifically focus on the link between energy prices and agricultural prices. Most of the modeling efforts are targeted towards policy design and the impacts of biofuel policies on land use change. Since scenario analysis of various policy options in a multiple energy price setting complicates the policy design, most modeling efforts rely on exogenous assumption on either transportation fuel demand or transportation fuel prices. In this respect, this work addresses a number of questions regarding the interaction of the agricultural and energy markets via biofuels, while also highlighting a number of uncertainties and areas for investigation that we enumerate below.

Starting from the end-use demand for light duty transportation energy, additional scenarios would be useful to explore other possible outcomes for FFV and E85 penetration. In particular, what would be the impact of assuming alternative distribution costs and infrastructure to enable ethanol to reach a wider range of end-use markets outside the Midwest? Alternatively, what would be the impact of assuming additional barriers to E85 distribution and uptake by FFVs? Additional research on FFV markets and owner preferences in fueling with E85 versus E10 would provide valuable insights into the possibilities for E85 volumes to expand beyond their currently modest levels. Also, scenarios could explore the impacts of non-ethanol pathways for advanced biofuels that would provide renewable gasoline or diesel via processes such as thermochemical conversion or biochemical conversion to hydrocarbon fuels. The coupling between the CARD and MARKAL frameworks would be useful here as well to capture the changes in the heavy duty vehicle fleet via MARKAL, which could utilize renewable diesel fuels from cellulosic feedstocks. The role of vehicle electrification via plug-in hybrids and electric vehicles is also critical, and affects the overall market for liquid fuels, for which crude oil and biomass-based fuels are currently competing to supply.

On the agricultural feedstock side, additional work should continue to explore the trade-offs between cellulosic feedstocks and traditional commodity crops like corn to explore their implications for energy markets, but probably more importantly, for their impacts on agricultural markets and the food versus fuel debate. In addition, this framework could be used to explore impacts of linking a wider range of cellulosic feedstocks to production of biofuels as well as the use of cellulosic feedstocks in other applications, such as for heat and electric power.

Finally, the integrated framework could be used to explore additional energy price scenarios or to simulate major changes coming from the agricultural markets. Examples could include alternative scenarios for cellulosic feedstock prices and availability, or higher corn prices triggered by factors such as drought, global demand for food and feed, or changes in projected yield increases.

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Appendix A. Supplementary Material

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.eneco.2015.06.008.

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