# Optimal Mix of Feedstock for Biofuels: Implications for Land Use and GHG Emissions

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**Abstract**

Increasing concerns about energy security and climate change mitigation have led to significant policy support for biofuels, particularly for cellulosic biofuels. This paper examines the short- and long-run effects of Renewable Fuel Standard (RFS) on the mix of biofuel feedstocks, food, fuel and wood markets and land use change by using an economic model that integrates the agriculture, forest and transportation fuel sectors. Our results show that RFS would lead to the production of about 1600 billion liters of corn ethanol over the 2010-2035 periods, which could constitute a maximum of two-thirds of the cumulative biofuel production; the remaining mandate is met by advanced biofuels. The logging and milling residues are the primary initial providers of biomass feedstocks. After year 2025, energy crops and crop residues will play the leading role in cellulosic feedstocks production. Producing these biofuels will not cause significant land use change between and within agricultural and forest sector as compared to the business-as-usual (BAU) case. While the RFS could significantly affect production, exports and prices of crop and livestock commodities relative to the BAU case, its impacts on the forest sector is found to be relatively small except for pulpwood related products in the long term. Overall, the RFS reduces cumulative social welfare over 2010-2035 periods by $78.8 Billion relative to the BAU case.

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## 1. Introduction

Biofuels have attracted increasing interest and won significant policy support over the last few decades. By year 2011, US became the global low-cost ethanol producer, manufacturing 13.2 billion gallons in which about 87% is corn ethanol. After initially being advocated as a promising strategy for energy security, rural economic development and climate change mitigation, grain-based biofuels production has since been implicated in driving up food prices and causing farmland shortage, water scarcity and deforestation (Mitchell, 2008; Searchinger, 2008; Fargione et al., 2008; Stone et al., 2010). This has led to U.S. biofuel policy shifting the focus from corn ethanol to non-grain based or second-generation cellulosic biofuel. In 2007, the Energy Independence and Security Act (EISA) imposes a Renewable Fuel Standard (RFS) that sets a goal of 36 billion gallons of biofuel production in 2022, of which 21 billion gallons must be "advanced biofuels".

Recently, a variety of cellulosic feedstocks have been promoted with more productive land use and lower GHG intensity (per liter). They are including crop residues like corn stover, wood chips, short rotation wood crops and high yielding herbaceous energy crops such as miscanthus and switchgrass. This has led to increasing concerns about the economic and environmental consequences of use of mixed feedstocks for ethanol production. Can these cellulosic feedstocks from joint agriculture and forest sectors together with corn meet the biofuel mandate without conflicting with food/feed production? How does limited land compete among food, forest and renewable fuel feedstocks? Additionally, whether the replacement of gasoline with ethanol in particularly cellulosic ethanol has positive or negative greenhouse gas (GHG) implications? These controversial questions are among critical issues in evaluating economic viability and environmental performance of biofuel production. The quantitative analysis of the effects of current biofuel policies on both agricultural and forest sectors, as well as GHG emissions is of much interest (e.g. BRDI, 2008; U.S. Department of Energy, 2011). However, little national-level research has well studied the response of joint agriculture and forest sectors to the RFS mandates in which significant target is found in the advanced biofuel production.

The objective of this paper is to examine the short- and long-run effects of policies promoting biofuel production on U.S. food, wood, and energy markets and on land use change using an economic model. More specially, we analyze the effects of biofuel policy on

(1) Spatial-temporal agricultural and forest biofuel feedstocks distribution

(2) Land transfers between and within the agricultural (including livestock) and forest sectors over time

(3) Domestic crop, livestock and forest production as well as food and forest products prices and economic welfare

## 2. Literature Review

Since the establishment of national-level mandates for biofuel use, considerable research has been conducted on examining the market and environmental implications including the supply and regional distribution of feedstock production and its effects on food and fuel prices, land use change and GHG emissions. However, existing studies usually focused on examining feedstocks from either the agricultural or the forestry sector. Taheripour et al. (2011) analyzed the land use changes induced by biofuel production from agricultural sector with the Global Trade Analysis Project (GTAP) model. Their results suggested that use of dedicated energy crops would induce land use change and transfer forest land and cropland pasture to crop production, whereas corn stover had no significant induced land use change. By applying the Biofuel and Environmental Policy Analysis Model (BEPAM), Chen et al.(2011a,b) found that the RFS would increase food prices as well as domestic social welfare and reduce GHG emissions relative to a no-policy, business-as-usual scenario. Corn ethanol could constitute a maximum of two-thirds of the cumulative biofuel production over 2007-2022, with the remaining being met by advanced biofuels. Total cropland was estimated to increase by 6% in 2022, most of which was due to increased corn production.

Woody biomass from forest materials is projected to have a significant potential for the production of bioenergy, biofuels and bioproduction (U.S. Department of Energy, 2011). The 2011 Billion-Ton Study (U.S. Department of Energy, 2011) estimated that about 320 million sustainable dry tons of biomass feedstock are available annually from forestlands, and by year 2022, forest biomass would account for 100 million dry tons at price $60/dry ton in renewable fuels production. However, very little conventional pulpwood is available at this price. The report by Biomass Research and Development Institute (2008) found that forestland could provide sufficient feedstock to produce 4 billion gallons of second-generation and other renewable fuels at the price ranging from $40 to $46 per dry ton. A variety of research both national- and regional-level has been dedicated to estimating the economic and land use effects of increasing wood biomass demand for renewable energy production with varied findings. Sedjo and Sohngen (2013) used the dynamic Timber Supply Model (TSM) to examine how the national forest market might respond to increased demands for wood biomass in meeting mandatory cellulosic biofuel production. They found that mandated increases in cellulosic biofuels would result in wood prices being 15-20% higher than business-as-usual case. In addition, there would be a 60% increase in raw wood consumption by 2022 and a sharp decline in the US wood balance of trade. Ince et al. (2011) examined the forest markets response to a range of national level renewable electricity standards by applying the U.S. Forest Products Model (USFPM). Under the assumption that wood biomass supported 1/3 of the simulated increase in bioelectricity, very limited impacts to timber product consumption or prices as well as forest inventories were found, which was mainly due to the projected logging and milling residues as the primary source of biomass feedstock supply. However, with the increased share of forest feedstock used to meet bioelectricity demand, they predicted more substantive impacts in the timber product markets. By applying the Sub-Regional Timber Supply (SRTS) model in three southern states (i.e. Alabama, Georgia and Florida), Abt et al. (2013) projected an approximate doubling of 2007 pulpwood price by year 2037 when a bioenergy demand was in place, and thus smaller declines in timberland and higher forest carbon sequestration in these three states. The above studies mainly focused on examining woody biomass but largely ignored the potential supply of agricultural biomass and its interactions with forest sector.

FASOM is among the very limited models which have a comprehensive coverage of both. By applying the recently updated model, Beach et al., (2012) investigated the bioenergy feedstocks optimal mix and the implications for land use and net GHG emissions. They found that under the baseline biofuel mandates scenario (without storage costs), by 2035, corn and miscanthus would be the primary feedstocks for over 94% of total ethanol production with additional contributions from bagasse (3%), refined sugar (1.8%) and milling residues from forest products production (1.2%). As the main contributor, miscanthus required considerably less land and generated a substantial and GHG mitigation benefit relative to other feedstocks. A recent study by White et al., (2013) applied the same model to evaluate the biomass production in both forest and agriculture sectors in support of a renewable electricity standard. The results revealed that forest sector was the largest initial provider of bioelectricity feedstock with a quickly transition to the energy crops after 2010. At the highest targets for bioelectricity production, an increased conversion of forest to agriculture land was found with moderate increase in forest and agriculture emissions.

In the present research, we examine the role of both cropland and forest feedstocks in meeting national-level renewable fuel standard by applying a newly developed economic model. The key extension of this model from FASOM is the integrated modeling of three markets, agriculture, forest and transportation fuel. This treatment allows for endogenous determination of the relative contribution of fossil fuel, agricultural and forest biomass in meeting transportation fuel demand and the extent to which biofuels can displace fossil fuels and mitigate GHG emoissions. In this paper, we focus our study mainly on the biomass used for meeting the renewable liquid fuels demands. However, it should be noticed that the use of cellulosic and other feedstocks in bioelectricity production can also compete with the use in the production of transportation fuels.

## 3. Methods

### 3.1 Model description

The economic model applied for this study is a dynamic, multi-market equilibrium model that integrates the existing agriculture-focused partial equilibrium model-Biofuel and Environmental Policy Analysis Model (BEPAM) with a forest sector model. The model determines the optimal land use and feedstock mix by maximizing the aggregated economic welfare subject to various resources balance and technological constraints for years 2010-2035 represented in five-year timesteps. The agricultural sector in the model includes all major conventional crops and livestock animals, four bioenergy crops (miscanthus, switchgrass, hybrid poplar and willow) and two crop residues (corn stover and wheat straw) at the 295 Crop Reporting District (CRD) level in the US. Five types of agricultural land (irrigated and non-irrigated cropland, idle cropland, cropland pasture and pasture land) are specified for each CRD.

Land availability is responsive to crop and livestock prices and marginal lands can be used for energy crop production. Cropland can move freely between production of alternative crops with no extra cost but subject to a convex combination of both historical and synthetic crop mixes (Önal and McCarl, 1991; Chen and Önal, 2012). Cropland pasture is eligible for crop production but with 1/3 less productivity relative to the regular cropland. The associated conversion cost of converting cropland pasture to cropland is set equal to the difference in their regional land rental rates based on the assumed equilibrium of land markets (Beach and McCarl, 2010). The opportunity cost of cropland for producing energy crops are determined endogenously as the difference between the pre-hectare revenues from the most profitable crop production practice (across different crop rotation and tillage) and associated production costs. Land conversion costs for producing energy crops on marginal land are assumed to be the returns to land from the least profitable crop production practice in each CRD due to the absence of empirical data (Chen, 2010). More details about agricultural sector can be found in BEPAM model description (Chen et al., 2011b).

The basic structure of forest sector largely follows the forest component in FASOM which was based on the family of timber assessment models (e.g. Timber Assessment Market Model (TAMM), North American Pulp and Paper Model (NAPP), Aggregate Timber Assessment System (ATLAS)). Timber inventory data and current and future timber yields were taken largely from the ATLAS inputs used for the 2000 RPA Timber Assessment (Beach and McCarl, 2010). They varied by 11 market regions across the conterminous United States. We then equally allocate the regional timber stocks into each CRD within that region for matching the agricultural land use. More than 40 major wood products (including logs) and associated manufacturing processes as well as trade between U.S. and Canada are included in this sector. Optimal decisions regarding forest management activities, harvesting year, and whether to replant or deforest are based on the relative returns to alternative actions. Currently, we assume that either logging residues (no more than 65% collection rate) or milling residues (including wood pulp) in this sector can be used to produce biofuel.

The fuel sector includes demand of vehicle kilometer travels (VKT) for five types of vehicles that use liquid fossil fuels (gasoline or diesel) blended with biofuels, including conventional gasoline, ethanol flex-fuel, hybrid, electric, and diesel vehicles. Supply of biofuels is met with four broad types, first generation ethanol, cellulosic ethanol, first generation biodiesel and second generation biomass to liquids diesel. The model endogenously determines the demands for liquid fossil fuels and biofuels given the energy contents of alternative fuels, the fuel economy of each type of vehicle and biofuel blend limits as specified by EIA (2010).

The agriculture and forest sectors are linked by competing for the private lands which can produce either agriculture or forest products. Meanwhile, they link with fuel sector by supplying biomass energy feedstocks to meet the biofuel demand for VKT. In the land-use change setting, we assume agriculture land including cropland, cropland pasture and pastureland can be converted to timber land or vice versa. Land movements depend on the net present value of returns to alternative uses, including the costs of land conversion. Generally, the land moves between sectors until the markets equilibrate and the net present value of land plus the investment cost to transfer land (land clearing, leveling, seedbed preparation, etc.) and any hurdle cost (Beach and McCarl., 2010). In our model, basic land conversion costs between agriculture and forest sector follow the value used in the recent FASOM model which was derived from data from Natural Resource Inventory by the Natural Resource Conservation Service (USDA, 2001). Additional hurdle cost is determined through calibrating 5-year land movements to the 2002-2007 observed level.

Our model keeps the advantages of agriculture and fuel sectors in BEPAM and comprehensive forest sector in FASOM. To accommodate this integration, four major modifications are made to previous BEPAM: (1) replacing 10-year rolling horizon in one-year timestep with 30-year rolling horizon in five-year timestep; (2) adding timber land into total land use and allowing for exchange with agricultural land (i.e. cropland, cropland pasture and pastureland) existing in BEPAM; (3) allowing land use change within agricultural land depending on the net present value of returns under each land type; (4) substituting woody biomass supply (logging residues and pulpwood ) which was exogenously implemented in BEPAM with endogenous forest inventory supply. In general, our model improves over existing analyses in several ways. First, it integrates three markets (agriculture, forest and fuel) and captures their interactions. Second, it accounts for a broader source of second generation biofuel feedstocks including dedicated energy crops, crop residues, short rotation woody crops and woody biomass. Third, it allows imperfect substitutability between gasoline and ethanol. Fourth, the recursive structure enables it to simulate future processing costs of biofuels production due to learning-by-doing.

### 3.2 Scenarios description

In this paper, we consider business-as-usual (BAU) and national-level RFS scenarios. The BAU scenario is defined as one without any biofuel policy. The RFS sets ethanol equivalent volumetric requirements for four categories of renewable fuels: corn-based ethanol, biomass-based diesel, cellulosic biofuels and advanced biofuels. According to the Annual Energy Outlook (EIA, 2010), however, the volumes of second generation as mandated by EISA are considered unlikely to be achieved by 2022, but to be exceeded by 2035. For this reason, we implement the biofuel production targets in our analysis based on the AEO projections for annual volumes of first and second generation biofules for the period 2010-2035. These projections set corn ethanol production at its upper limit of 15 billion gallons in 2015 and beyond and total renewable fuel production at 47 billion gallons in 2035 (Figure 1). In addition, we assume that commercial cellulosic biofuel production will be feasible from 2015 onwards.

## 4. Results

### 4.1 Biomass supply

To meet the biofuel mandates, a mix of feedstocks is found, where the mix differs over time and regions. Under RFS scenario, the 15-billion-gallon corn ethanol mandate is binding over all years after 2015; the remaining mandate is met by advanced biofuels. The optimal mix of various cellulosic feedstocks over years is shown in Table 1. The forest sector is projected to be the primary initial (before 2025) provider of cellulosic feedstocks, in which logging residues contribute the largest quantities followed by milling residues. With time progressing and increasing biofuel demand, feedstocks from agricultural sector tend to be the major providers. The largest agricultural biomass provider is projected to be crop residues in year 2025 and quickly transit to the dedicated energy crops after 2025. The amount of logging residues used for biofuel production reaches the peak value between 2025 and 2030 and ranges from 15.7 million dry metric ton to 22.1 million dry metric ton. Pulpwood for biofuel use enters feedstocks mix in 2025 and reaches the highest amount (12.7 M MT) in 2030. Generally, in the presence of RFS, cellulosic biofuel production is projected to play an increasing role in total feedstocks mix with increased reliance on energy crops and crops residues. Feedstock supply from woody biomass increases with years and attains the highest value in 2030. A slight decrease in woody biomass is shown in 2035 which is largely due to the growth and total availability of harvestable forest inventory.

The variety of feedstocks is projected to distribute among different regions represented in our model. Table 2 presents the spatial distribution of cumulative cellulosic feedstocks production between 2010 and 2035 in RFS scenario. Corn stover comes primarily from the Midwest states, followed by Plain states. Production of miscanthus and switchgrass are more concentrated in the Great Plains followed by Southern region. Southern region provides the largest volume of woody biomass (residues and pulp) which accounts for more than 80% of total national productions. Generally, the Plains region is found to be the major producer for dedicated energy crops, while a significant amount of woody biomass is produced in the Southern region.

### 4.2 Land Use Change

Increases in national-level biofuel demand are projected to yield moderate changes in land use relative to the BAU case. Under RFS, total crop land in 2035 is about 3 million hector (M Ha) more than the BAU case and the increased area is largely for energy crops production. There is 6 M Ha of cropland pasture being converted to produce energy crops in compare to only 0.15 M Ha used for field crops production. Land exchange between the agriculture and forest sectors is also found in both BAU and RFS scenarios. Table 3 shows the projected cumulative levels of afforestation and deforestation in different regions under BAU and RFS scenarios between 2010 and 2035. In the BAU case, total afforested land is found to be 15.7 M Ha with more than 60% occurring in the southern region and largely (>75%) from forest pastureland. The national deforestation area is projected to be 0.23 M Ha by year 2035, which is mainly from conversion of forest land to cropland. Increasing demand for biofuel under RFS scenario leads to about 2 M Ha more deforested land going to cropland relative to the BAU, most of which is found in Midwest. Meanwhile, projected national afforestation decreases by about 1.7 M Ha and the largest decrease is found in the southern region.

### 4.3 Market implications

We find that market impacts of RFS differ by commodities in each sector. Table 4 presents the production and price of major crop, livestock and forest commodities under BAU and RFS scenarios. RFS leads to the increase in demand for corn and thus results in an increase in corn production in 2035 by 24% relative to the BAU. However, corn price in 2035 is still 8% higher than BAU as 32% of corn production is used for biofuel production. Increased prices are found for soybean, wheat and beef in 2035 than the BAU due to the reduction in their production levels. As a result of RFS mandate, 56.8 liters corn ethanol, 62.4 liters cellulosic ethanol and 32.4 liters biodiesel are projected to be produced in 2035, while domestic production of gasoline and diesel falls by 7.5% and 13.6%, respectively and producer price for each reduces by 9.8% and 19%, respectively. In compared to the significant impacts found in agricultural and fuel sectors, RFS has minor effects on major wood products production and price. RFS increases the wood pulp production by averagely 8%, while the amounts of Oriented Strand Board (OSB) and paper production are less relative to the BAU case. The diversion of harvested (hard) pulpwood from current paper and panel uses into uses for biofuel leads to the 45% higher price of hardwood pulp relative to the BAU case in southern region by 2035. More details of the amount of national hardwood pulp uses for conventional (paper and panel) products and biofuels in BAU and RFS scenarios by years are presented in Table 5. More manufactured hardwood pulp relative to BAU is found since 2025, however there is less used for conventional paper and panel industry.

We assess the cumulative discounted social welfare under alternative scenarios over the 2010-2035 periods by summing the total consumers' and producers' surpluses in all three sectors and government revenues from fuel taxes/subsidies. Increasing prices for conventional crops plus increasing demand for crop residues and energy crops benefit agricultural producers. However, the surplus of gasoline producers is reduced due to the lower demand for gasoline and price compared to BAU. As a result, the RFS scenario results in a lower social welfare between 2010 and 2035 by $78.8 Billion (0.2%) relative to the BAU scenario.

## 5. Conclusions

Biofuel policies have been enacted to provide benefits for energy security and GHG mitigation. Increasing concerns regarding changes of land use and commodity prices and the implications of GHG emissions coming with the expansion of first- and second- generation biofuels production have therefore raised. However, it is still uncertain as to how the agricultural and forest sectors might respond to the increased demand for biofuel feedstocks and the potential environmental consequences. In this paper, we develop an economic model integrating agriculture, forest and fuel sectors to examine the economic variability of various feedstocks under RFS policy and the extent to which biofuel expansion will affect the optimal mix of feedstocks, food and fuel prices, GHG emissions and social welfare.

Our results show that RFS would lead to the production of about 1600 billion liters of corn ethanol over the 2010-2035 periods, which could constitute a maximum of two-thirds of the cumulative biofuel production; the remaining mandate is met by advanced biofuels. The logging and milling residues in forest sector are the primary initial providers of biomass feedstocks. After year 2025, the agriculture sector will contribute the majority of biomass feedstocks mostly via energy crops such as miscanthus and crop residues. Regarding the spatial distribution of feedstocks, Midwest is the major producer of corn stover, while production of energy crops (miscanthus and switchgrass) is more concentrated in the Great Plains. Southern region provides the largest volume of woody biomass (residues and pulp) which accounts for more than 80% of total national productions.

Increases in biofules production will not cause significant changes in land use between and within agricultural and forest sectors relative to the BAU case. There will be an approximately 3% increase in total cropland by 2035 due to the biofuel mandates, which would be met mostly by an increase in cropland at the extensive margin and through reductions in land under pasture. The cumulative deforested land between 2010 and 2035 is projected to increase by 2 M Ha and largely is found in Midwest.

While the RFS could significantly affect production, exports and prices of crop and livestock commodities relative to the BAU case, its impacts on the forest sector is found to be relatively small except for pulpwood related markets in the long term. Increased demand of biofuel drives up the price of hardwood pulp and paper by 2035. Overall, total social welfare in RFS scenario over 2010-2035 periods is $78.8 Billion lower than in the BAU case.

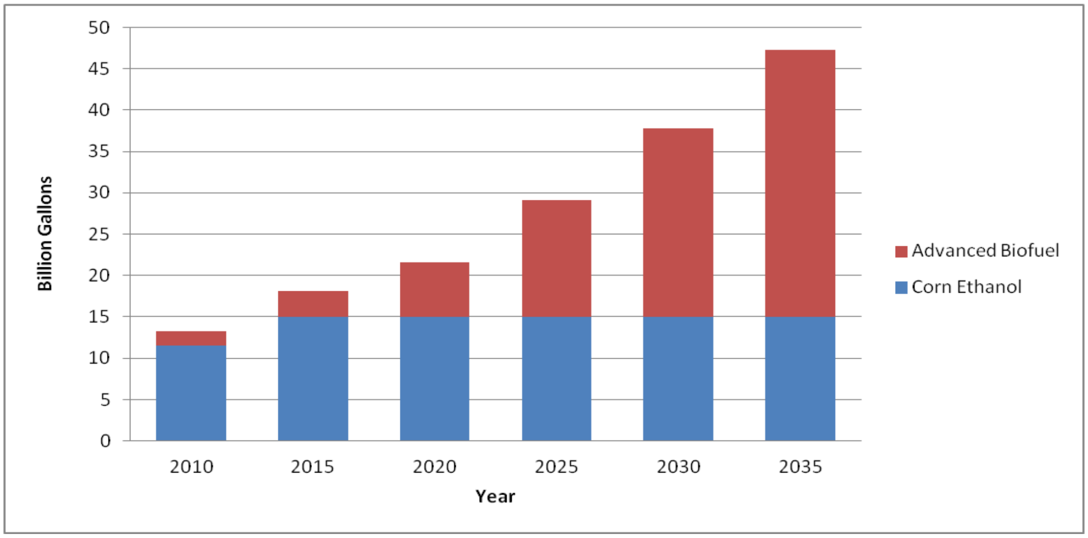


**Figure 1.** National biofuel use mandates from 2010 to 2035 (Source: EIA, 2010).

**Table 1**. Projected cellulosic biofuel feedstock mixes by years under RFS scenario.

| **(M MT)** | **2015** | **2020** | **2025** | **2030** | **2035** |
|---|---|---|---|---|---|
| **RFS** | | | | | |
| Crop residues | 0 | 10.5 | 22.9 | 74.0 | 97.8 |
| Miscanthus | 0 | 10.9 | 69.5 | 93.3 | 166.5 |
| Switchgrass | 0 | 0 | 0.3 | 14.3 | 24.1 |
| SRWC[1] | 0 | 0 | 0.02 | 0.02 | 2.3 |
| Logging residues | 15.7 | 18.5 | 21. 1 | 22.1 | 21.2 |
| Milling residues | 0 | 6.5 | 18.9 | 18.0 | 17.9 |
| Pulp | 0 | 0 | 0.3 | 12.0 | 12.0 |
| **Sum** | 15.7 | 46.4 | 133.0 | 233.72 | 341.8 |

[1] SRWC=Short-rotation woody crops

**Table 2.** Spatial distribution of cumulative cellulosic feedstocks production between 2010 and 2035 under RFS scenario.

| (M MT) | Southern | Midwest | Plains | Western | PNW[1] | Northeast |
|---|---|---|---|---|---|---|
| **RFS** | | | | | | |
| Corn Stover | 9.1 | 123.9 | 79.5 | 2.5 | 0 | 0 |
| Wheat Straw | 1.5 | 2.3 | 10.4 | 9.3 | 0.4 | 0 |
| Miscanthus | 114.1 | 18.0 | 176.5 | 0 | 0 | 0.4 |
| Switchgrass | 1.5 | 0 | 37.2 | 0 | 0 | 0 |
| SRWC | 0 | 1.5 | 0 | 0 | 0 | 0.9 |
| Logging residues | 79.2 | 4.5 | 0 | 2.8 | 3.3 | 8.5 |
| Milling residues | 69.5 | 0 | 0 | 5.8 | 8.3 | 0 |
| Pulp | 21.5 | 0 | 0 | 0.1 | 3.4 | 0 |

[1] PNW= Pacific Northwest

**Table 3.** Projected levels of afforestation and deforestation by regions under different scenarios, 2010-2035.

| (M Ha) | BAU | RFS |
|---|---|---|
| Cropland to Forest | 0.6 | 0.4 |
| Cropland Pasture to Forest | 2.8 | 2.5 |
| Forest Pasture to Forest | 12.3 | 11.1 |
| **Sum of Afforestation** | 15.7 | 14.0 |
| | | |
| Forest to Cropland | 0.2 | 2.2 |
| Forest Pasture to Cropland | 0.03 | 0.02 |
| **Sum of Deforestation** | 0.23 | 2.22 |

**Table 4.** Projected commodity production and prices in 2035 under different scenarios.

| **Scenarios** | **BAU** | **RFS** |
|---|---|---|
| | Commodity | Production |
| **Agriculture (M MT)** | | |
| Corn | 360.0 | 445.7 |
| Soybean | 110.2 | 100.6 |
| Wheat | 84.2 | 75.8 |
| Beef | 21.7 | 21.5 |
| | | |
| **Forest** | | |
| Softwood Pulp (M Cu m) | 125.2 | 133.1 |
| Hardwood Pulp (M Cu m) | 87.3 | 97.7 |
| Oriented Strand Board (M Sq Ft) | 16.4 | 16.2 |
| Uncoated Paper (M MT) | 13.3 | 12.6 |
| Coated Paper (M MT) | 3.8 | 2.7 |
| | | |
| **Fuel (B Liters)** | | |
| Gasoline | 189.8 | 175.5 |
| Diesel | 199.7 | 172.6 |
| Corn Ethanol | 15.3 | 56.8 |
| Cellulosic Ethanol | 0 | 62.4 |
| Biodiesel | 1.0 | 32.4 |
| | Commodity | Prices |
| **Agriculture ($/MT)** | | |
| Corn | 123.9 | 133.5 |
| Soybean | 323.6 | 354.2 |
| Wheat | 219.2 | 226.3 |
| Beef | 1491.3 | 1526.3 |
| | | |
| **Forest** | | |
| Softwood Pulp (South) ($/ Cu m) | 120.7 | 113.2 |
| Hardwood Pulp (South) ($/Cu m) | 16.3 | 23.7 |
| Oriented Strand Board ($/Sq Ft) | 170.3 | 158.8 |
| Uncoated Paper ($/ MT) | 775.7 | 799.5 |
| Coated Paper ($/ MT) | 686.9 | 700.0 |
| | | |
| **Fuel ($/Liter)**[1] | | |
| Gasoline | 0.9 | 0.8 |
| Diesel | 1.1 | 0.9 |
| Corn Ethanol | 0.6 | 0.7 |
| Cellulosic Ethanol | 0.7 | 0.8 |
| | | |
| | Social | Welfare ($B ) |
| | 33979.9 | 33901.1 |

[1] Producer Price

**Table 5.** Manufactured national hardwood pulp by different uses and years under BAU and RFS scenario.

| (M MT) | BAU | | | RFS | | |
|---|---|---|---|---|---|---|
| Hardwood Pulp | **For Conventional Industry** | **For Biofuel** | **Total** | **For Conventional Industry** | **For Biofuel** | **Total** |
| **2010** | 92.9 | 0 | 92.9 | 91.7 | 0 | 91.7 |
| **2015** | 94.1 | 0 | 94.1 | 91.0 | 0 | 91.0 |
| **2020** | 90.8 | 0 | 90.8 | 90.5 | 0 | 90.5 |
| **2025** | 90.0 | 0 | 90.0 | 89.7 | 0.3 | 90.0 |
| **2030** | 92.5 | 0 | 92.5 | 89.2 | 12.7 | 101.9 |
| **2035** | 87.3 | 0 | 87.3 | 85.7 | 12.0 | 97.7 |

## References

Abt, K.L., R. C. Abt., and C. Galik. 2012. “Effect of Bioenergy Demands and Supply Response on Markets, Carbon, and Land Use.” *Forest Science.* 58(5): 523-539.

Beach, R.H. and B. A. McCarl. 2010. “U.S. Agricultural and Forestry Impacts of the Energy Independence and Security Act: FASOM Results and Model Description.” Final report prepared for US Environmental Agency.

Beach, R.H., Y. W. Zhang and B. A. McCarl. 2012. “Modeling Bioenergy, Land Use, and GHG Emissions with FASOMGHG: Model Overview and Analysis of Storage Cost Implications.” *Climate Change Economics.* 3,1250012 (2012).

Biomass Research and Development Institute (BRDI). 2008. “Increasing Feedstock Production for Biofuels: Economic Drivers, Environmental Implications, and the Role of Research.” Report prepared by the Biomass Research and Development Board Feedstock Inter-Agency Working Group. P.167.

Chen, X. 2010. “A Dynamic Analysis of U.S. Biofuels Policy Impact on Land Use, Greenhouse Gas Emissions and Social Welfare.” PhD dissertation, University of Illinois at Urbana-Champaign.

Chen, X., H. Huang, M. Khanna and H. Önal. 2011a. “Meeting the Mandate for Biofuels: Implications for Lad Use, Food and Fuel Prices.” Working paper 16697, National Bureau of Economic Research.

Chen, X., H. Huang, M. Khanna and H. Önal. 2011b. “Alternative Transportation Fuel Standards: Welfare Effects and Climate Benefits.” Working paper, Social Science Research Network.

Chen, X and H. Önal. 2012. “Modeling Agricultural Supply Response Using Mathematical Programming and Crop Mixes.” *American Journal of Agricultural Economics*. 94 (3): 674-686.

Energy Information Administration (EIA). 2010. “Annual Energy Outlook 2010: with projections to 2035.” U.S. Energy Information Administration, Office of Integrated Analysis and Forecasting, U.S. Department of Energy, Washington, DC, 2010.

Fargione, J., J. Hill., D. Tilman., S. Polasky., and P. Hawthorne. 2008. “Land Clearing and the Biofuel Carbon Debt.” *Science.* 319: 1235-1238.

Ince, P.J., Kramp, A.D., Skog, K. E., Yoo, D-I., and V. A. Sample. 2011. “Modeling Future U.S. Forest Sector and Trade Impacts of Expansion in Wood Energy Consumption.” *Journal of Forest Economics.* 17, 142-156.

McCarl, B.A., and U.A. Schneider. 2000. "US Agriculture's Role in a Greenhouse Gas Emission Mitigation World: An Economic Perspective," *Review of Agricultural Economics,* 22(1), 134-159.

Mitchell, D. 2008. “A Note on Rising Food Prices.” World Bank Policy Research Working Paper. Washington, DC.

Searchinger, T., R. Heimlich, R.A. Houghton, F. Dong, A. Elobeid., J. Fabiosa., S. Tokgoz., D. Hayes., and T. Yu. 2008. “Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land-Use Change.” *Science.* 319: 1238-1240.

Sedjo, R. A., and B. Sohngen. 2013. “Wood as a Major Feedstock for Biofuel Production in the United States: Impacts on Forests and International Trade.” *Journal of Sustainable Forestry.* 32:1-2, 195-211.

Stone, K.C., P.G. Hunt, K.B. Cantrell., and K.S. Ro. 2010. “The Potential Impacts of Biomass Feedstock Production on Water Resource Availability.” *Bioresource Technology.* 101: 2014-2025.

Taheripour, F., W. Tyner., and M. Q. Wang. 2011. “Global Land Use Changes due to the U.S. Cellulosic Biofuel Program Simulated with GTAP Model.” Working paper, Purdue University.

Önal, H., and B. A. McCarl. 1991. "Exact Aggregation in Mathematical Programming Sector Models." *Canadian Journal of Agricultural Economics* 39: 319-334.

U.S. Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS). 2001. *1997 National Resources Inventory Summary Report*. USDA, NRCS. 90 p.

U.S. Department of Energy. 2011. “U.S. Billion Ton Update: Biomass Supply for a Bioenergy and Bioproducts Industry.” Oak Ridge National Laboratory, Oak Ridge, TN. ORNL/TM-2011/224, P.227.

White, E. M., G. Latta., R. J. Alig., K. E. Skog., and D.M. Adams. 2013. “ Biomass Production from the U.S. Forest and Agriculture Sectors in Support of a Renewable Electricity Standard.” *Energy Policy*. 58: 64-74.