Modeling Alternative Policies for Forestry and Agricultural Bioenergy Production and GHG Mitigation

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Abstract

A key consideration for development of energy and climate policy affecting the forestry and agricultural sectors is that the selection of specific mechanisms implemented to achieve bioenergy production and/or greenhouse gas (GHG) mitigation targets may have substantial effects on landowner incentives to adopt alternative practices. For instance, the prices of allowances and offsets are expected to diverge under some policies being considered where there is a binding cap on the quantity of offsets from the agricultural and forest sectors. In addition, provisions that limit or exclude specific practices from receiving carbon payments will affect the quantity and cost of GHG mitigation opportunities available. In this study, the recently updated Forest and Agriculture Sector Optimization Model with GHGs (FASOMGHG) was used to estimate GHG mitigation potential for private land in the contiguous U.S. under a variety of GHG price policies. Model scenarios suggest that U.S. forestry and agriculture could provide mitigation of 200 – 1000 megatons carbon dioxide equivalent per year (Mt CO_2e/year) at carbon prices of \$15 to \$50/tCO_2e. Binding limits on offsets have increasingly large effects on both the total magnitude and distribution of GHG mitigation across options over time. In addition, discounting or excluding payments for forest sinks can reduce annualized land-based mitigation potential 37-90 percent relative to the full eligibility scenario whereas discounting or excluding agricultural practices reduces mitigation potential by less than 10 percent.

Keywords: Climate policy, energy policy, FASOMGHG, GHG mitigation

JEL Classification: C61, Q42, Q54

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1. Introduction

Forestry and agricultural activities are widely recognized as potential low-cost greenhouse gas (GHG) mitigation options, particularly in the near term while alternative energy technologies are in the development stage. Changes in forestry and agriculture practices can reduce and avoid the atmospheric buildup of the three most prevalent GHGs directly emitted by human actions: carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). The removal of atmospheric CO_2 through sequestration in carbon "sinks" is a mitigation option in forestry and agriculture that has received particular attention in recent United States climate change legislative proposals as well as policies introduced by the international community. However, the level of GHG mitigation available from the forestry and agriculture sectors is dynamic and can differ substantially as a result of market phenomena or policy actions that influence land use.

An important but frequently overlooked issue in developing guidelines for the inclusion of forestry and agriculture is the implications of selecting specific mechanisms through which mitigation is achieved. For instance, whether these sectors are allocated allowances under a cap-and-trade system or provide mitigation through an offset market will potentially have significant effects on mitigation, land use, commodity production, and prices. This may be particularly important in the case of bioenergy, where the use of forest and agricultural feedstocks would reduce emissions from regulated sectors and would reduce the consuming entities need for allowances rather than serve as an offset. In addition, energy prices as well as separate bioenergy policies (e.g., renewable portfolio standards (RPS) or renewable fuel standards), have important interactions with policies focused on GHG mitigation for these sectors.

Because policy provisions are likely to cause the market prices for allowances and offsets to increasingly diverge over time, the design of bioenergy and GHG mitigation policy has important implications for the mix and volume of mitigation options adopted. In addition, provisions that limit or exclude specific practices will affect the quantity and cost of mitigation opportunities available. In this study, we analyze the impacts of alternative GHG mitigation policy designs and study the effects of competing policies and developments using the Forest and Agricultural Sector Optimization Model with Greenhouse Gases (FASOMGHG) model. FASOMGHG is well-suited for this type of analysis given its comprehensive coverage of economic and biophysical systems within both the forest and agricultural sectors. FASOMGHG and its predecessor model ASM have been applied in numerous studies dating back to the 1970s and the model has been widely used for GHG mitigation policy analyses (EPA, 2005; Lee, 2002; McCarl and Schneider, 2001) and in examining the role of offsets in an economy-wide climate policy (EPA, 2007, 2008, 2009a). Our results highlight the importance of energy and climate policy design for land use, commodity prices, and GHG mitigation.

2. Background

U.S. forests and agricultural lands currently provide a large net carbon sink estimated at 1063 teragrams[1] (Tg) of CO_2 equivalent (CO_2 e) per year (EPA, 2009b), enough to offset roughly 15 percent of U.S. GHG emissions. However, after accounting for agricultural non-CO_2 emissions (CH_4 and N_2O), the forest and agriculture sectors offset about 8.6 percent of total U.S. GHG emissions (EPA, 2009b). The forestry and agricultural sectors can provide GHG mitigation above the baseline sink through reduced emissions (e.g., changes in soil nutrient management, manure management), increased sequestration (e.g., afforestation, forest management, reduced tillage), or by providing feedstocks that substitute for fossil fuels (bioenergy production) as discussed in McCarl and Schneider (2001). These contributions are not typically included under the national GHG cap in current legislative initiatives, but these sectors may provide offsets or lower emitting goods that can help emitters in meeting the cap.

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[1] One teragram equals one million metric tons.

Expanding mitigation in the forestry and agricultural sectors can potentially reduce the cost of compliance[2], but the level is dynamic and can change considerably due to natural events, market conditions or changes in policies that impact land use. Changes in U.S. farm policy, renewable fuel mandates, and domestic or international demand/supply shifts can move lands into and out of agricultural production inducing shifts in crop mix, production practices and mitigation potential. Forest disturbances such as fires, pests, and disease outbreaks can reduce the carbon sequestered in forests. In addition, projected increases in population and income are expected to continue placing development and product demand pressure on both forested and agricultural lands.

Additionally, energy and climate policy will play key roles in shaping the future of these sectors. In previous analyses of the quantity of offsets potentially available from the forestry and agricultural sectors, it has often been assumed that all available mitigation options would be fully credited and would receive the same carbon price. However, while there is interest in the use of forest and agriculture based mitigation (FAM) to reduce the cost of meeting GHG mitigation targets, there are also concerns about "flooding the market" with cheap FAM that will discourage emissions reductions in covered sectors and with leakage and additionality discounts to ensure that the credits paid for are equivalent to net GHG mitigation. Thus, there have been policy suggestions to limit the quantity of FAM (particularly sequestration) that can be applied.

As described above, alternative FAM activities may fall under either the market for allowances or the market for offsets. In the absence of limits, the price per unit of carbon equivalent for allowances and offsets would be expected to equilibrate. However, because domestic legislation under consideration has typically placed limits on the share of mitigation that can be met using domestic (and international) offsets, the prices of allowances and offsets are expected to diverge. In equilibrium, the allowance price is equal to the marginal cost of abatement for sectors that fall under the cap, while the price of offsets is equal to the marginal cost of providing offsets by sectors that do not fall under the cap to the allowable limit. As the cap is lowered over time, the allowance price tends to increase substantially whereas the offset price remains fairly constant (e.g., EPA, 2009). While the reduction in the number of allowances is expected to increase the marginal cost of abatement, limitations on offsets as a constant quantity per year or as a percentage of total allowances implies that constant or declining quantities of offsets will be demanded. Thus, the marginal cost of providing those offsets is expected to remain relatively constant over time. As a result, there will be strong incentives for landowners to adopt practices that provide GHG mitigation into the allowance market rather than the offset market over time.

Here, we use the FASOMGHG dynamic partial equilibrium model of the U.S. forest and agricultural sectors to investigate the issues raised above by simulating the GHG mitigation portfolio provided under a variety of carbon price scenarios with varying divergence of allowance and offset prices over time as well as excluding or discounting specific FAM practices.

3. Methods

We use FASOMGHG to estimate the GHG mitigation potential for U.S. forests and agriculture. Earlier versions of the model have been used for numerous analyses, including a major EPA study of GHG mitigation (EPA, 2005).[3] The model has recently undergone substantial enhancements to develop a more detailed representation of the U.S. forestry and agricultural sector. Key improvements include an expanded bioenergy sector that models more than twenty feedstocks used for the production of biodiesel,

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[2] For instance, EPA analyses of the Lieberman-Warner Climate Security Act (S.2191) found that the use of offsets can significantly reduce the cost of economy-wide climate policy. A scenario with unlimited domestic and international offsets was found to reduce the marginal cost of GHG reductions by 71 percent relative to the base case limiting domestic and international offsets to 15 percent. Allowing no offsets increased the marginal cost by 93 percent.

[3] See Adams et al. (2005) for additional documentation of FASOMGHG and previous model applications.

starch- and sugar-based ethanol, cellulosic ethanol, and electricity (Beach and McCarl, 2008). Other improvements on the agricultural side include updates to rates of technological change, input costs, and output prices to reflect the current state of the market. In the forestry component of the model, there have been updates for 5 year time steps, timberland stocks, distribution of land ownership, and harvest schedules. From a GHG accounting standpoint, the number of categories has been expanded to account for more than 50 categories of stocks and fluxes in forestry and agriculture, that can be summed up to 7 major categories: afforestation, forest management, soil carbon sequestration, biomass-based reductions in emissions from energy use,[4] CH_4 and N_2O-specific practices such as enteric fermentation and fertilizer management, CO_2 from fossil fuels emitted during agricultural production, and carbon sequestered on developed land. Finally, the assumptions about growth in demand for developed land have been updated to reflect recent projections of income and population growth. This section summarizes the general structure and data sources of FASOMGHG that is used in this paper to look at regional climate change mitigation policies.

3.1 Model Overview

FASOMGHG assumes intertemporal optimizing behavior by economic agents. The model solves an objective function to maximize discounted net market surplus, represented by the dynamic area under the product demand functions (an aggregate measure of consumer welfare) less the area under factor supply curves (an aggregate measure of producer costs). Such an approach involves solving a nonlinear programming model with endogenous product and factor prices. The resultant objective function value is consumers' plus producers' surplus. Landowners are assumed to have perfect foresight and base decisions in a given period on the net present value of the future returns to alternative activities. For instance, the decision to continue growing a stand rather than harvesting it now is based on a comparison of the net present value of timber harvest from a future period versus the net present value of harvesting now and replanting (or not replanting and shifting the land to agricultural use). Similarly, landowners make a decision to keep their land in agriculture vs. afforestation based on a comparison of the net present value of returns in agriculture and forestry. Land can also move between cropland and pasture depending on relative returns. This process establishes a land price equilibrium across the sectors (reflecting productivity in alternative uses and land conversion costs) and, given the land base interaction, a link between contemporaneous commodity prices in the two sectors as well.

The model solution portrays simultaneous multi-period, multi-commodity, multi-factor market equilibria, typically over 70 to 100 years on a 5-year time step basis when running the combined agriculture-forest version of the model. Results yield a dynamic simulation of prices, production, management, consumption, GHG effects, and other environmental and economic indicators within these sectors under each scenario defined in the model run.

The key endogenous variables in FASOMGHG include

- commodity and factor prices;
- production, consumption, export and import quantities;
- land use allocations between sectors;
- management strategy adoption;
- resource use;
- economic welfare measures;

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[4] These reductions represent the net emissions saved from substituting feedstocks for fossil fuels in the transportation and electric power sectors after accounting for GHGs emitted while processing and transporting the biomass.

- producer and consumer surplus,
- transfer payments,
- net welfare effects; and
- environmental impact indicators:
- GHG emission/absorption of CO_2, CH_4, and N_2O and
- total nitrogen and phosphorous applications.

FASOMGHG quantifies the stocks of CO_2 and non-CO_2 GHGs emitted from, diverted by using bioenergy feedstocks, and sequestered by forestry and agriculture, plus the CO_2 stock on lands in the model that are converted to developed use. In addition, the model tracks GHG emission reductions in selected other sectors that result from mitigation actions in the forest and agricultural sectors. For instance, the FASOMGHG bioenergy feedstock component accounts for reduced GHG emissions from fossil fuel use in the energy sector due to the supply of renewable bioenergy feedstocks from forestry and agriculture.

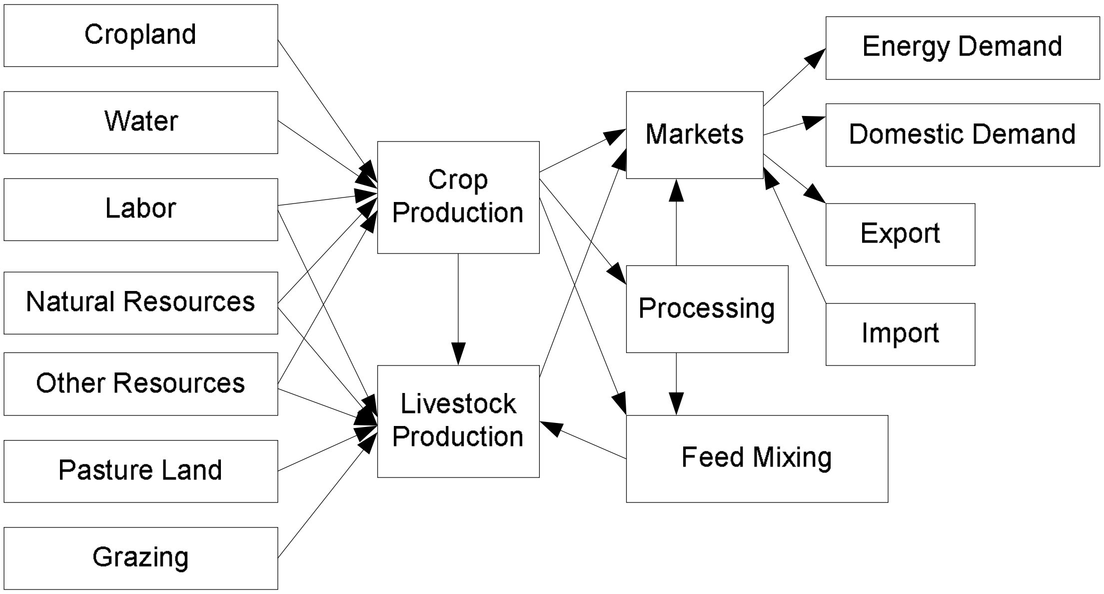
3.2 Model Structure

Examining the dynamic effects of policies affecting the forestry and agricultural sectors requires an analytical framework that can simulate the time path of market and environmental impacts. FASOMGHG simulates a dynamic baseline and simulates changes from that baseline in response to changes in public policy or other factors affecting the sector. FASOMGHG combines component models of agricultural crop and livestock production, bioenergy production, livestock feeding, agricultural processing, log production, forest processing, carbon sequestration, GHG emissions, wood product markets, agricultural markets, GHG payments, and land use to systematically capture the rich mix of biophysical and economic processes that will determine the technical, economic, and environmental implications of changes in policy, including large-scale expansion of renewable fuels production. FASOMGHG covers private timberlands and all agricultural activity across the conterminous (“lower 48”) United States, broken into 11 market regions, and tracks five forest product categories and more than 2,000 production possibilities for field crops, livestock, and bioenergy.

The basic conceptual framework of the agricultural sector in FASOMGHG is presented in Figure 1. Land, water, labor, and natural and other resources (e.g., fertilizer, capital) are used by forest, crop (including bioenergy feedstocks), and livestock production. The raw primary commodities are then produced, and some move directly to markets, while others are used as inputs to processing activities generating secondary commodities (including bioenergy) on direct livestock feeding or are used in producing blended livestock feeds. The primary and secondary commodities, bioenergy commodities, blended feeds and imports go to meeting household demand, other domestic demand, livestock feeding, and exports.

FASOMGHG includes all states in the conterminous United States, broken into 63 subregions for agricultural production and 11 market regions (see Table 1). The 11-region breakdown reflects the existence of regions for which there is agricultural activity but no forestry, and vice versa. Forestry production is included in 9 of the market regions (all but Great Plains and Southwest), whereas agricultural production is included in 10 of the market regions (all but Pacific Northwest—West side). The Great Plains and Southwest regions are kept separate because they reflect important differences in agricultural characteristics. Likewise, there are important differences in the two Pacific Northwest regions (PNWW, PNWE) for forestry, so they are maintained separately, although only the PNWE region is considered a significant producer of agricultural commodities tracked in the model.

Figure 1. FASOMGHG Agricultural Sector Modeling Structure



The land base included in FASOMGHG is all cropland, pastureland, rangeland, and private timberland[5] throughout the conterminous United States. On the agricultural side, four major types of land are specified[6]:

Cropland is land suitable for crop production. The 1997 U.S. Department of Agriculture (USDA) National Resource Inventory (NRI) data (most recent NRI dataset that is publicly available at a spatially disaggregated level) coupled with USDA National Agricultural Statistics Service (NASS) data on county-level harvested acreage were used to specify land availability.

Conservation Reserve Program (CRP) land is specified as land enrolled in the Conservation Reserve Program. Land in the CRP is generally marginal cropland retired from production and converted to vegetative cover, such as grass, trees, or woody vegetation to conserve soil, improve water quality, enhance wildlife habitat, or produce other environmental benefits. However, it is possible for this land to move back into cropland as landowner commitments to maintain land in CRP expire.

Pastureland is that suitable for livestock pasture from cropland pasture, public land, and forestland pasture. Rangeland is also accounted for. These land areas are converted on an animal unit basis where the animal units from various land types are adjusted to meet current demand.

Agricultural land is allowed to move from the cropland pasture inventory into the cropland category and vice versa. The conversion costs of moving between cropland and pasture are set at the present value of the difference in the land rental rates between the alternative uses based on the assumed equilibration of land markets.

In addition, cropland is also tracked by crop tillage system and irrigated/dryland status and the duration of time it has been in such a system to allow tracking of sequestered soil carbon and the transition to a new soil carbon equilibrium after a change in tillage.

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[5] Although public timberland is not explicitly modeled because the focus of the model is on private decision-maker responses to changing incentives, FASOMGHG includes an exogenous timber supply from public forestlands.
[6] FASOMGHG is currently undergoing updates in land use accounting that will provide additional detail on different types of pasture and rangeland.

Table 1. Definitions of 11 Market Regions in FASOMGHG

Key	Region	States/Subregions
NE	Northeast	Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, West Virginia
LS	Lake States	Michigan, Minnesota, Wisconsin
CB	Corn Belt	All regions in Illinois, Indiana, Iowa, Missouri, Ohio (IllinoisN, IllinoisS, IndianaN, IndianaS, IowaW, IowaCent, IowaNE, IowaS, OhioNW, OhioS, OhioNE)
GP	Great Plains	Kansas, Nebraska, North Dakota, South Dakota
SE	Southeast	Virginia, North Carolina, South Carolina, Georgia, Florida
SC	South Central	Alabama, Arkansas, Kentucky, Louisiana, Mississippi, Tennessee, Eastern Texas
SW	Southwest (agriculture only)	Oklahoma, All of Texas but the Eastern Part (Texas High Plains, Texas Rolling Plains, Texas Central Blacklands, Texas Edwards Plateau, Texas Coastal Bend, Texas South, Texas Trans Pecos)
RM	Rocky Mountains	Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, Wyoming
PSW	Pacific Southwest	All regions in California (CaliforniaN, CaliforniaS)
PNWE	Pacific Northwest—East side (agriculture only)	Oregon and Washington, east of the Cascade mountain range (agriculture only)
PNWW	Pacific Northwest—West side (forestry only)	Oregon and Washington, west of the Cascade mountain range (forestry only)

FASOMGHG tracks private timberland throughout the United States. Timberland refers to productive forestlands able to generate at least 20 cubic feet of live growing stock per acre per year and that are not reserved for uses other than timber production (e.g., wilderness use). Lands under forest cover that do not produce at least 20 cubic feet per acre per year, called unproductive forestland, and timberland that is reserved for other uses are not considered part of the U.S. timber base and are therefore not tracked by the model. In FASOMGHG, endogenous land use modeling is only done for privately held parcels, not publicly owned or managed timberlands. The reason is that management of public lands is significantly influenced by government decisions on management, harvesting, and other issues that account for multiple public uses of these lands rather than private responses to market conditions. However, an exogenous quantity of timber harvested on U.S. public lands is accounted for within the model. Regional public harvest levels are set at exogenous levels based on past harvesting within the region and timber inventory levels for public timberlands are simulated based on the exogenous timber harvest levels that are assumed to be set by government administrative decree. The public land managers could change allowable harvest levels at any time, but those changes are not predictable, so harvest is assumed to remain fixed over time.

Private timberland is tracked by its quality and its transferability between forestry and agricultural use. FASOMGHG includes three different site classes to reflect differences in forestland productivity. These site groups were defined based on ATLAS inputs (Haynes, Adams, and Mills, 1995), where yields vary substantially between groups.

FASOMGHG also tracks land ownership including two private forest owner groups: forest industry (FI) and nonindustrial private forests (NIPF). The traditional definitions are used for these ownership groups: industrial timberland owners are those that possess processing capacity for the timber, and NIPF owners do not.

In addition, FASOMGHG tracks land in terms of the type of timber management, the species on the land, and the stand age. There are 18 different possible management intensity classes depending on whether thinning, partial cutting, passive management, or other management methods are used. There are also 25 different forest species types, which vary by region (e.g., Douglas fir and other species types in the West and planted pine, natural pine, and various hardwood types in the South). Stand age is explicitly accounted for in 5-year cohorts ranging from 0 to 4 years up to 100+ years.

3.3 Temporal Scope and Dynamics

FASOMGHG is typically run for periods of 70 to 100 years to depict land use, land transfers, and other resource allocations between and within the U.S. agricultural and forest sectors. The model solution portrays a multi-period equilibrium on a 5-year time step basis. As noted earlier, FASOMGHG incorporates deterministic expectations of future prices, or perfect foresight, where expected future prices are identical to the prices that are realized in the future. Thus, landowners are able to foresee and account for the consequences of their land use, management, and production decisions on future commodity prices and incorporate that information into their decisions. It is assumed that producers maximize the net present value of future returns. The results from FASOMGHG yield a dynamic simulation of prices, production, management, consumption, and GHG effects within these two sectors under the scenarios defined for a particular model run.

Given the long rotation lengths in forestry, an important consideration for modeling the dynamics of landowner decision making is the possibility that trees could be planted with a rotation length that exceeds the amount of time remaining in a model simulation. Producers would need to anticipate net returns that justify keeping land in forestry (or moving land from agriculture to forestry) and incurring stand establishment costs in order to plant trees. To account for cases where the anticipated harvest date of a stand that could potentially be planted in a given period is past the end date being explicitly modeled,[7] "terminal conditions" must be defined. Terminal conditions represent the projected net present value of an asset for all time periods after the end of the explicit model projection. Several types of terminal assets are valued in FASOMGHG, including (a) initial timber stands that are not harvested during the simulation period, (b) reforested stands remaining at the end of the simulation period, and (c) agricultural land retained in agriculture.

FASOMGHG also incorporates a number of assumptions regarding changes in yields, production costs, and demand over time. Assumed rates of technological progress that vary by commodity are included based on historical yield growth and projections of future yields. In addition, certain processing activities, particularly those that rely on relatively new technologies, are expected to experience increases in production efficiency and corresponding reductions in processing costs in the future. For these

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[7] For instance, if a stand with a 30-year rotation were being considered in year 90 of a 100-year simulation, the anticipated harvest date would fall outside the time period modeled, and the producer would not receive revenue from harvesting (and would therefore not be expected to plant trees in this period in the absence of terminal conditions assigning a value to future harvests).

activities (e.g., cellulosic ethanol production), processing yields (quantity of secondary product output per unit of primary commodity input) and production costs are assumed to increase over time at rates that vary by process. Finally, domestic and export demand are assumed to change over time at growth rates that vary across commodities based on historical experience and USDA projections.

Simultaneous changes assumed for each of these variables over time are reflected in the baseline simulation. Changes in yield, production and processing costs, and demand over time will alter the relative returns to production of different commodities and will affect producer decisions. Other things being equal, for commodities where demand is growing faster than productivity, real prices will tend to be increasing over time. For commodities where demand growth is slower than productivity improvements, real prices will generally be trending downward. Of course, these changes in relative returns will lead to shifts in land allocation and production practices until the point where a new equilibrium is reached.

3.4 Greenhouse Gas Accounting

GHG mitigation opportunities in forestry and agriculture include activities such as afforestation (tree planting), forest management (e.g., altering harvest schedules or management inputs), forest preservation, agricultural soil tillage practices, grassland conversion, grazing management, riparian buffers, bioenergy substitutes for fossil fuels, fertilization management, and livestock and manure management. FASOMGHG includes a detailed GHG accounting component, quantifying the stocks of CO_2, CH_4, and N_2O that are sequestered by and emitted from the agriculture and forestry sectors along with the stock of lands that are converted for development. In addition, the model tracks changes in GHG emissions in selected other sectors resulting from forestry and agriculture. For instance, the model accounts for reduced GHG emissions from the fossil fuel use in the energy sector associated with an increase in production of renewable bioenergy feedstocks. GHG accounting in FASOMGHG accounts for stocks and fluxes in 60 categories, including 18 categories in the forest sector CO_2 in forest ecosystem pools, harvested wood products, timber production, and developed land, and 42 categories in the agricultural sector tracking CO_2, CH_4, and N_2O in agricultural ecosystems and feedstocks, crop and bioenergy production, and livestock management.

Table 2 summarizes the major categories of GHG sources and sinks included within FASOMGHG and identifies whether there are opportunities to reduce emissions, sequester carbon, or substitute for fossil fuel use associated with each category as well as the GHGs affected. Sequestration activities can enhance and preserve carbon sinks and include afforestation, forest management, and agricultural soil tillage practices. Agricultural sources of CH_4, N_2O, and fossil fuel CO_2 can be reduced through changes in fertilizer applications and livestock and manure management or alterations in other cropping practices. CO_2 emissions can be reduced by substituting renewable feedstocks, such as selected crops, crop residues, switchgrass, and short-rotation tree species, for fossil fuels to generate electricity or transportation fuels.

For reporting purposes in this paper, the categories are further combined into 7 major categories: forest management, afforestation, agricultural soil carbon sequestration, agricultural CH_4 and N_2O emissions, fossil fuel substitution with bioenergy, fossil fuel use in agricultural production, and carbon sequestration on developed land.

In addition to quantifying GHG emissions and sinks, FASOMGHG can also distinguish the unique time dynamics and accounting issues of carbon sequestration options. These include non-permanence issues such as saturation (or equilibrium level) of carbon sequestration over time, potential reversibility of carbon benefits, and fate of carbon stored in products after forest harvest. These can be compared with options for agricultural non-CO_2, fossil fuel CO_2, and bioenergy that do not exhibit saturation or reversibility and are permanent reductions.

Table 2. Major Categories of GHG Sources and Sinks in FASOMGHG

Source/Sink	Category of Potential Mitigation	CO_2	CH_4	N_2O
Forestry				
Afforestation	Sequestration	X		
Reforestation	Sequestration	X		
Timberland management	Sequestration	X		
Harvested wood products	Sequestration	X		
Agriculture				
Manure management	Emission		X	X
Crop mix alteration	Emission, Sequestration	X		X
Crop fertilization alter.	Emission, Sequestration	X		X
Crop input alteration	Emission	X		X
Crop tillage alteration	Emission, Sequestration	X		X
Grassland conversion	Sequestration	X		
Irrigated/dryland mix	Emission	X		X
Rice acreage	Emission	X	X	X
Enteric fermentation	Emission		X	
Livestock herd size	Emission		X	X
Livestock system change	Emission		X	X
Bioenergy				
Conventional ethanol	Fossil Fuel Substitution	X	X	X
Cellulosic ethanol	Fossil Fuel Substitution	X	X	X
Biodiesel	Fossil Fuel Substitution	X	X	X
Bioelectricity	Fossil Fuel Substitution	X	X	X
Development				
Carbon on developed land	Sequestration	X		

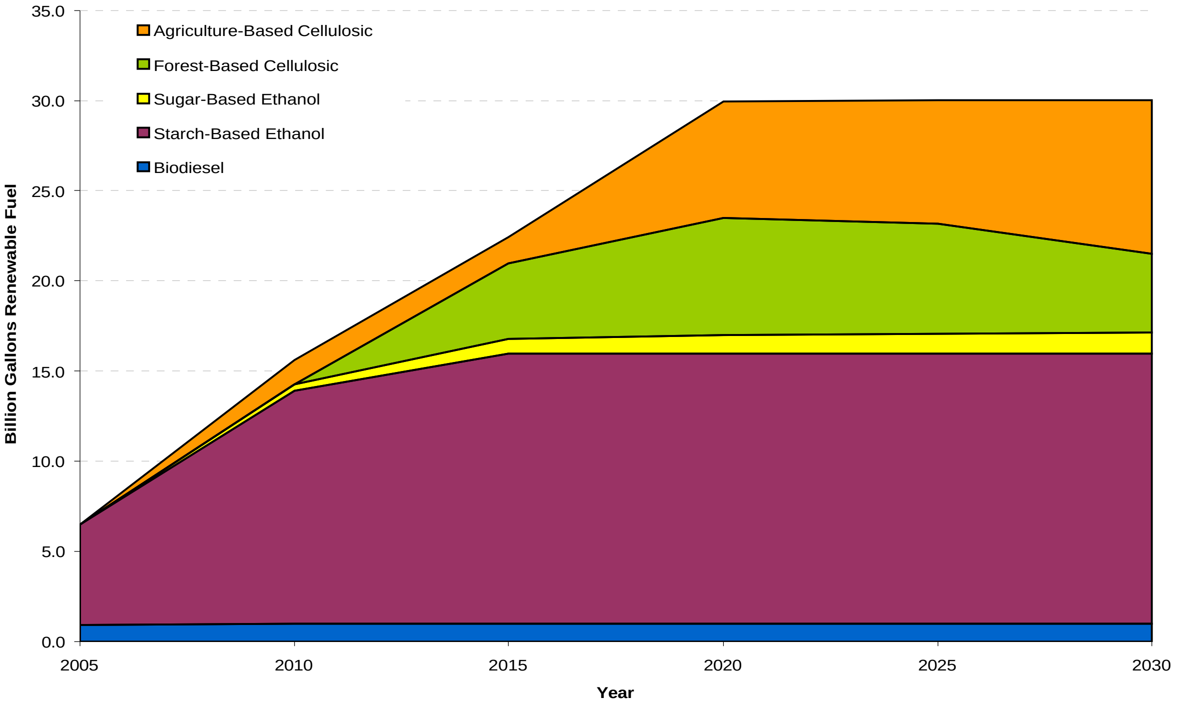
4. Model Baseline and Description of Policy Scenarios

This section describes selected FASOMGHG results for the model baseline as well as summarizing the specific policy scenarios examined in this paper.[8]

4.1 Model Baseline

Under the renewable fuel standards being proposed to meet the requirements of the Energy Independence and Security Act of 2007 (EISA), the use of biomass feedstocks is expected to increase over time as production of renewable biofuels is required to reach 36 billions gallons per year by 2022. Of that total requirement, we assumed that 30 billion gallons would be derived from U.S. forestry and agricultural feedstocks, with the remainder coming primarily from municipal waste and imports. Incorporating the EISA requirements into FASOMGHG increases baseline biofuels production over time, as shown in Figure 2, where production climbs from 6 billion gallons in 2005 to 30 billion gallons in 2022.

Figure 2. Types of Biofuels used to Meet RFS2 Baseline Volumes in FASOMGHG



Baseline GHG estimates with EISA requirements met, but without a carbon price, are shown in Figure 3. Results indicate that the new baseline differs from previous applications of the model (EPA 2005), which generated estimates that were consistently greater than or equal to net emissions in the updated model. Differences in the projected emissions can be attributed to changes in global GDP growth, population, consumer preferences (e.g., greater demand for meat), technological change, tillage practices, and an increase in the mandate for renewable fuels, among other things. Apparent in the figure is that fluxes from agriculture are relatively consistent, with non-CO_2 gases contributing a majority of the emissions. Additionally, because there is a strong demand for agricultural commodities and biomass feedstocks in the early periods, private timberland is estimated to be a source of emissions in 2010 before

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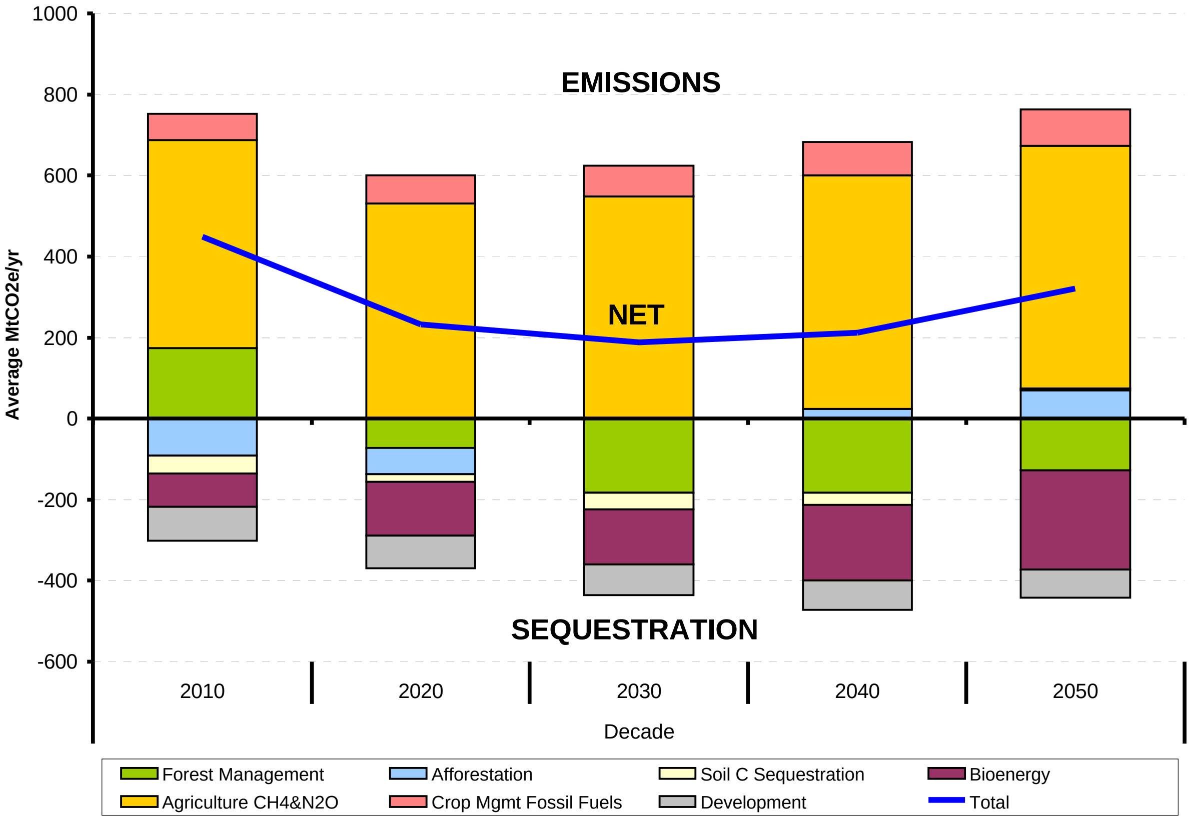
[8] As noted previously, results presented in this paper are preliminary. Model development and analysis is ongoing and the baseline and policy scenario results are subject to change as additional model updates and analyses are completed.

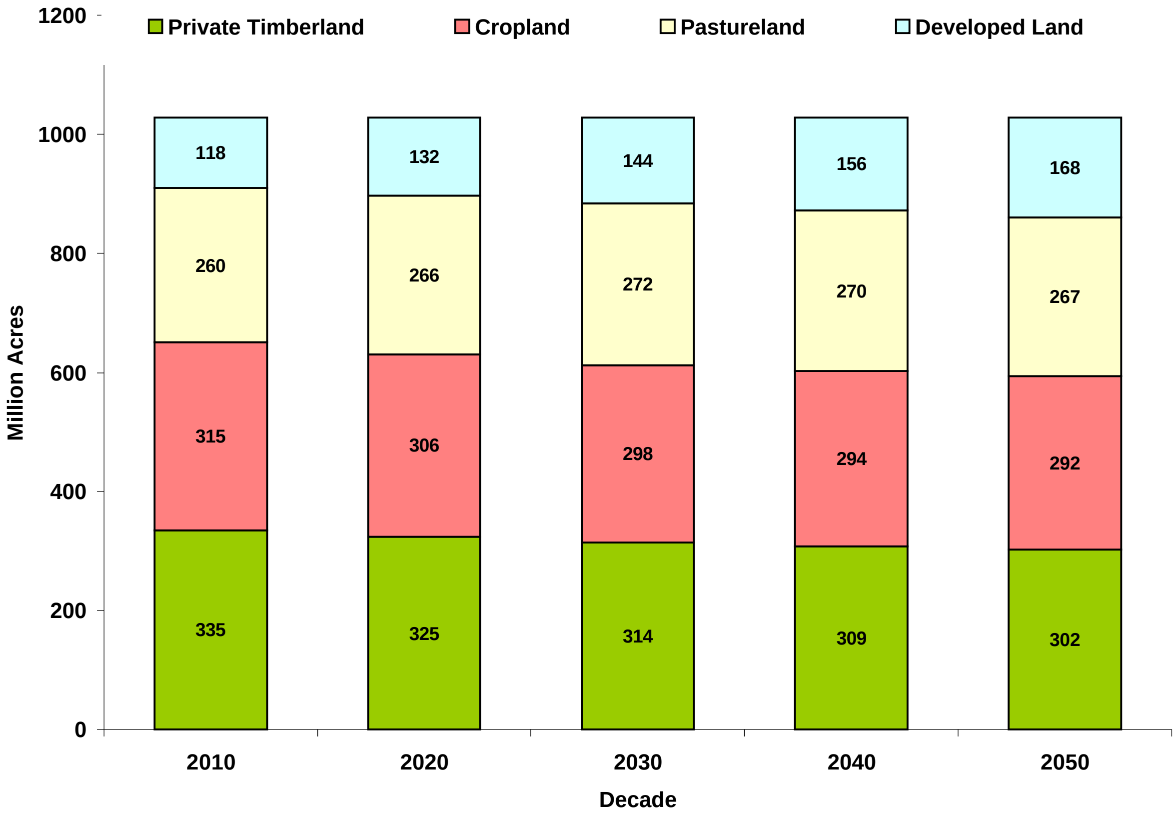
reverting back to its conventional role as a net sink. Baseline biomass use in bioenergy production increases over time as cellulosic ethanol production increases due to EISA requirements.

Figure 3. FASOMGHG Baseline GHG Emissions (MtCO2e/yr)



FASOMGHG baseline private land use for the conterminous U.S. is presented in Figure 4, and shows that private timberland and cropland diminish as land is converted for developed uses while pastureland remains relatively constant. The area of developed land increases over time due to increases in population and income, leading to ongoing reductions in total land available for forests and agricultural. In the baseline, private timberland and cropland tend to decline over time while pasture area increases due to increasing crop productivity over time (reducing the land area required to meet consumer demand) in combination with increased demand for livestock products.

Figure 4. FASOMGHG Baseline Land Use (Million Acres)



4.2 Policy Scenarios

For our examination of the potential of different mitigation practices and their role in markets, we apply the model to simulate equilibrium outcomes over the next century under a wide range of alternative CO_2 equivalent (CO_2e) prices for allowances and offsets. The GHG prices in this analysis are varied to evaluate the total GHG mitigation potential from these sectors at different economic incentive levels and can be combined to identify the mix of practices in a cost-effective mitigation portfolio. Mitigation potential is reported as changes from baseline trends, starting in 2010 and projected out 50 years in five year time steps. The first set of scenarios assumes that GHG prices remain constant for the duration of the policy at prices ranging from $15 to $50 per metric ton CO_2e. The second group of scenarios assumes that GHG prices will rise over time until they reach an exogenous price cap. The dynamic price path of these policies is outlined in Figure 5.[9] The rising price scenarios provide valuable insight on the potential changes in landowner behavior and a delay of action that could occur in this forward looking model. This study also investigates the mitigation potential when using a combination of rising allowance prices and constant offset prices.

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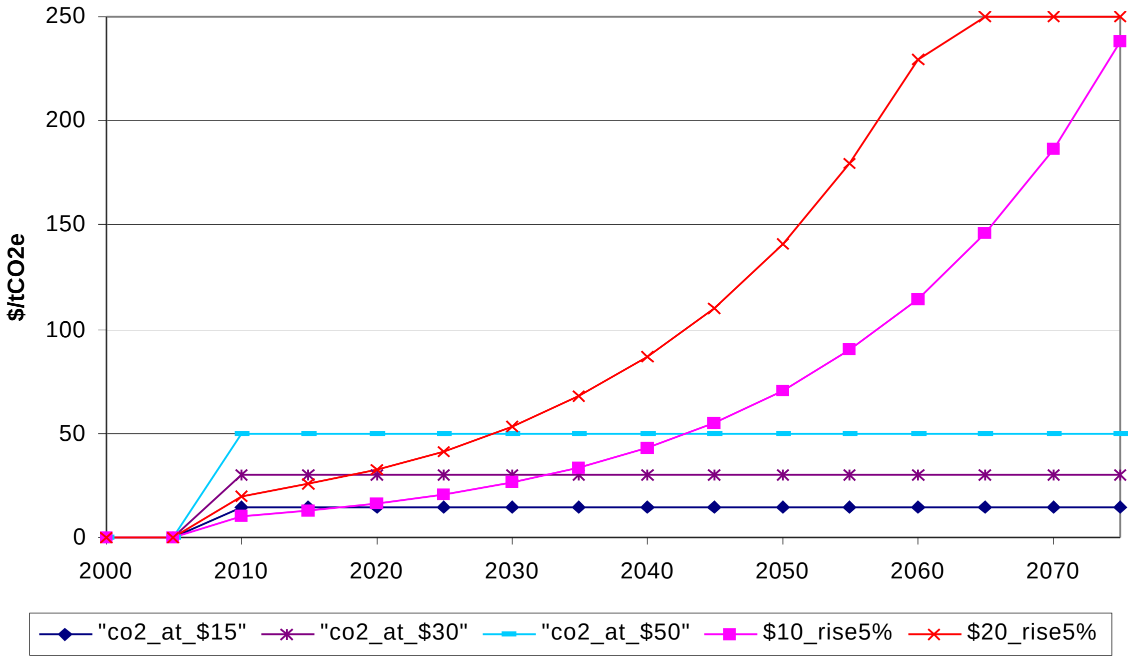
[9] We focus on representative results from selected runs in this paper.

Figure 5. Carbon Prices over Time under Alternative Scenarios



We also examined a variety of policy options that vary the eligibility of alternative mitigation practices for carbon payments to estimate changes in total mitigation and mix of options adopted. Under our full eligibility scenarios, all domestic mitigation opportunities included in the model are eligible for carbon payments based on the full value of their reduction in GHG. In the combination price scenarios, a rising GHG price is applied to bioenergy and agricultural fossil fuel combustion emissions, while a constant price is applied to all other activities.

It is also possible that some practices would not be eligible for carbon payments due to difficulties with such things as measurement and monitoring, leakage, or other implementation issues. Our limited eligibility scenarios assume that only afforestation and manure management are eligible offsets, though carbon prices also apply for mitigation options available to sectors likely included under a greenhouse gas cap in that they are related to the substitution or reduction of fossil fuel combustion. Specifically, these options include bioenergy production and fossil fuel use in agricultural production. Another option for addressing the uncertainties regarding net GHG mitigation for specific practices is to discount the carbon credits associated with those practices. Under our discounted eligibility scenarios, all options receive carbon payments, but those excluded from the limited eligibility scenarios receive discounted payments of only 50% of the carbon price that those options included under the limited eligibility scenarios receive. In addition, we explored additional scenarios where either forest or agricultural emissions were excluded or discounted or both. Across all of these eligibility scenarios, we present results for constant carbon prices of $15, $30, and $50/tCO$_2$e from 2010 to 2050.

5. Policy Results and Discussion

As described above, the carbon policy scenarios modeled assumed various combinations of offset and allowance carbon as well as a variety of different combinations of mitigation option eligibility for the forestry and agricultural sectors.[10]

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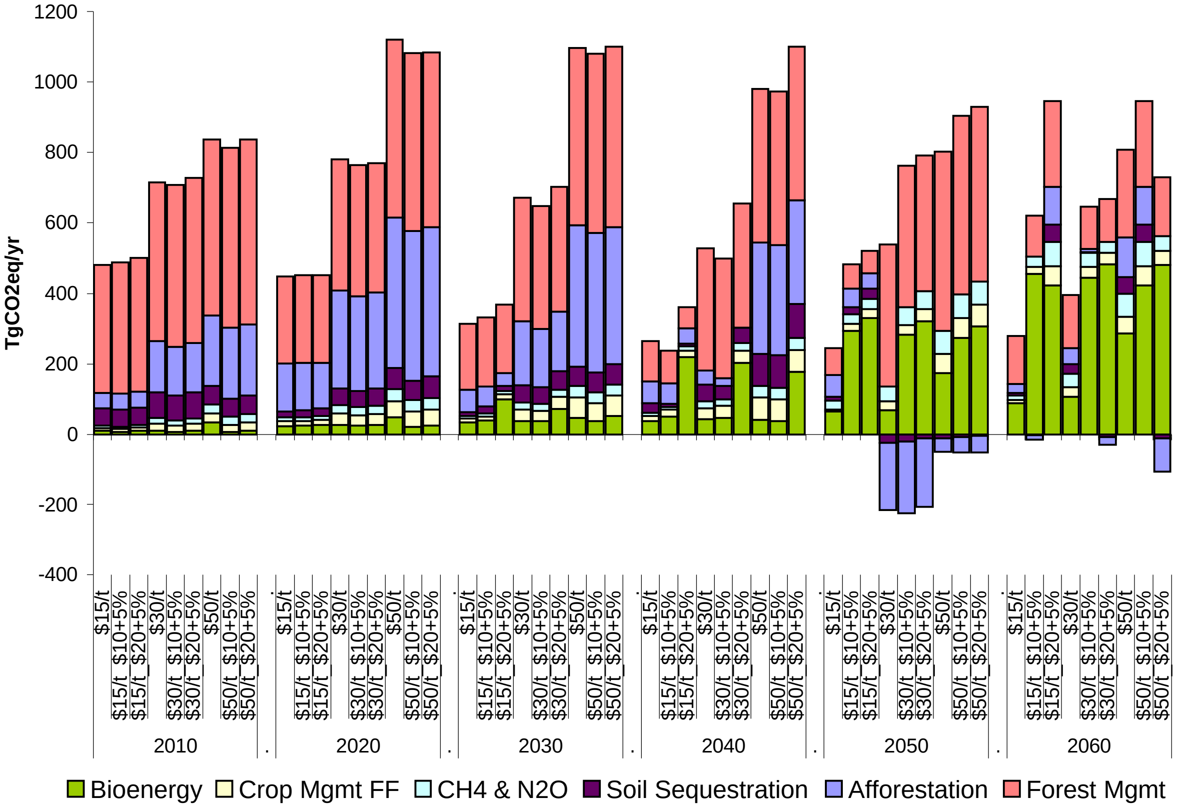
[10] Current results presented in this paper are preliminary. Model development and analysis is ongoing and the results are subject to change as additional model updates and analyses are completed

Figure 6 shows simulated GHG mitigation potential for several different carbon price paths and combinations of allowance and offset prices. At a carbon price of $50/tCO_2e, mitigation potential averages almost 1000 Mt CO_2e/year. There is relatively little difference between the scenarios with differing prices in the allowance and offset markets in early years, but both total mitigation and the mix of mitigation options become increasingly divergent over time as the gap between the carbon prices in the two markets increases. As expected, the mitigation reductions associated with provision of feedstocks for bioenergy are larger when the allowance price is rising over time relative to the offset price. Afforestation provides large quantities of mitigation in early years, but provides a smaller sink or a source in later decades as the afforested lands are harvested. Although reductions in fossil fuel use in the agricultural sector are also credited at the allowance price, there is relatively little responsiveness in fossil fuel use.

Figure 6. FASOMGHG GHG Mitigation Potential with Different Combinations of Carbon Price Paths (MtCO2e/yr), 2010-2060



Note: $15/t, $30/t, and $50/t denote constant carbon prices at those levels applied to both allowance and offset markets. The rest of the labels denote combinations of constant offset prices and rising allowance prices in the format "constant offset price_2010 allowance price+annual increase in allowance price until reaching cap", e.g., $15/t_$10+5% indicates that allowances receive a constant price of $15/tCO_2e whereas allowances are priced at $10 in 2010 and increase at a rate of 5% per year afterwards until reaching a maximum of $250/ tCO_2e.

As shown in Figure 7, the proportion of forestry and agricultural mitigation attributable to mitigation options that are in the allowance market increases over time even at a constant carbon price as improvements in yields make bioenergy a more attractive mitigation option over time. In cases with rising allowance prices, the majority of forestry and agricultural mitigation is taking place with options that fall under the allowance market by 2050 and they account for 74-84% of mitigation potential by 2060. In large part, this is due to the fact that it is economical to harvest timber around 2050 and new forest growth, and the associated sequestered carbon included in the offset market, accumulates gradually in subsequent years.

Figure 7. Proportion of Forestry and Agricultural Mitigation for Capped Emissions, $30/tCO2e Offset Price

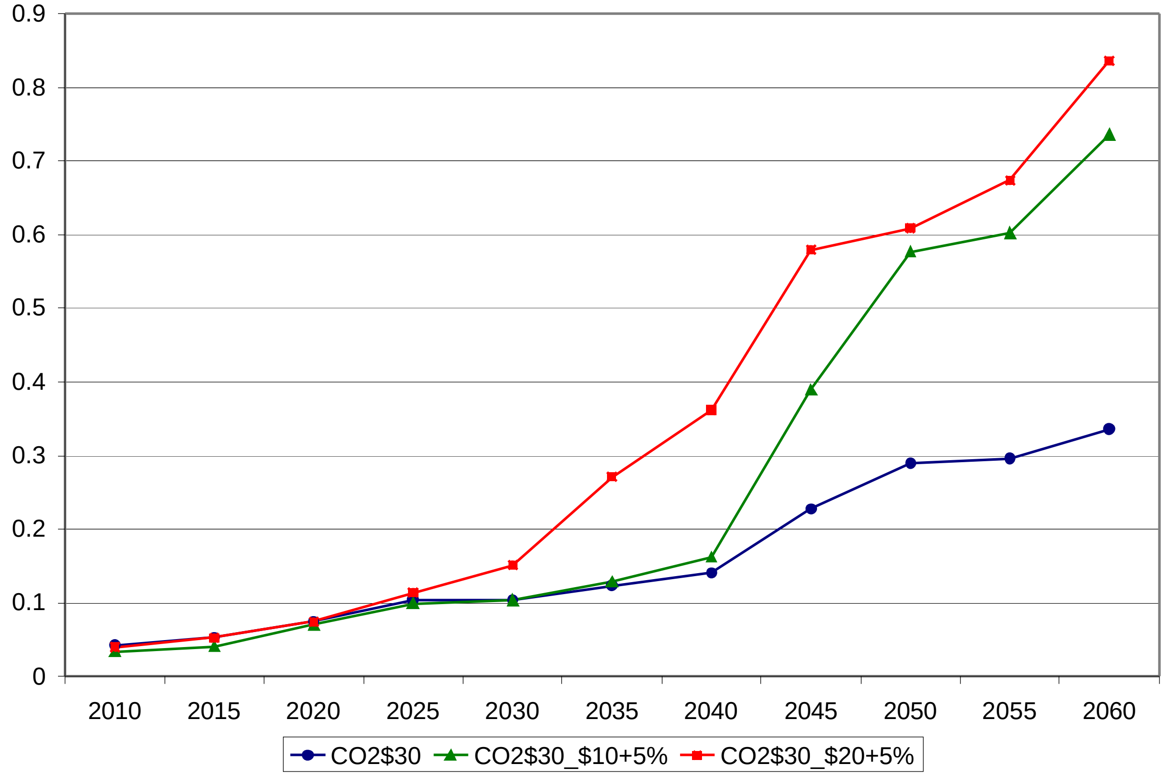


Figure 8 shows the relative amount of total mitigation simulated as well as mitigation coming from options providing allowances and from those providing offsets when allowance prices are rising relative to a case where allowance and offset prices are both constant at $30/tCO$_2$e. Total mitigation increases by more than 50 percent in later years when allowance prices are rising, with mitigation from those practices competing in the allowance market rising to about four times as high as with a constant price and mitigation from practices providing offsets falling to less than half their levels with a constant allowance price by 2060. This reflects shifts in land use and mitigation options chosen as relative prices of alternative mitigation options change over time.

Having separate prices for allowances and offsets seems to have relatively little effect on land use change over the next few decades, but begin to induce decreases in private timberland and pasture relative to cropland starting around 2040 (see Figure 9). Increased bioenergy production increases the relative returns to cropland relative to other uses, although there is still net movement of land in timberland in all years and all cases.

Figure 8. Mitigation from Combination Price Scenarios Relative to Constant Price of $30/tCO2e

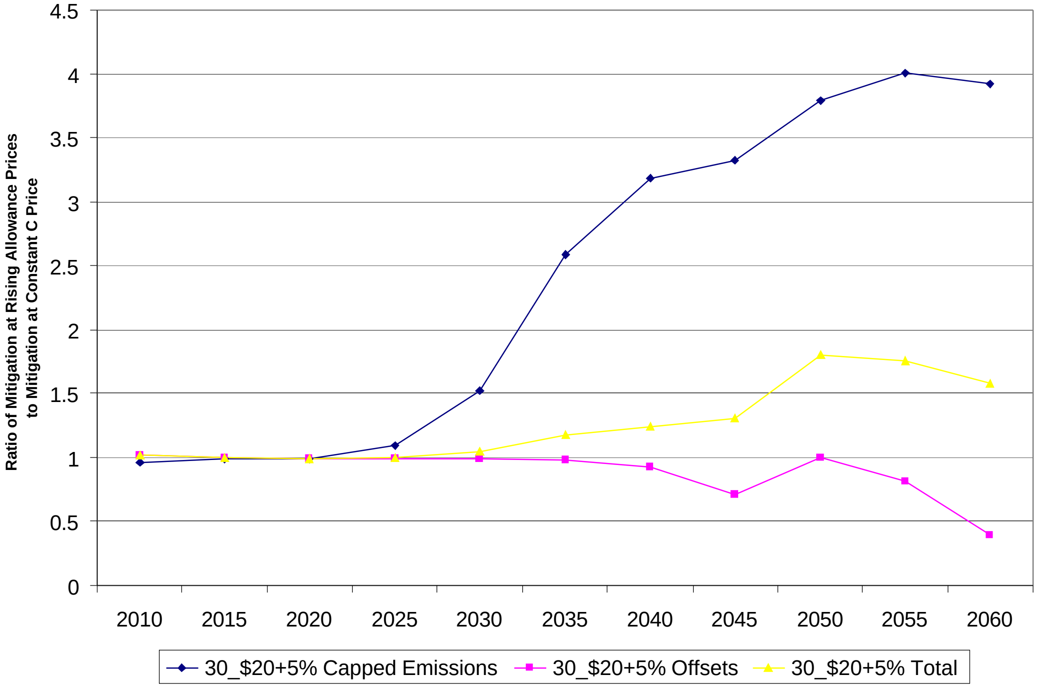
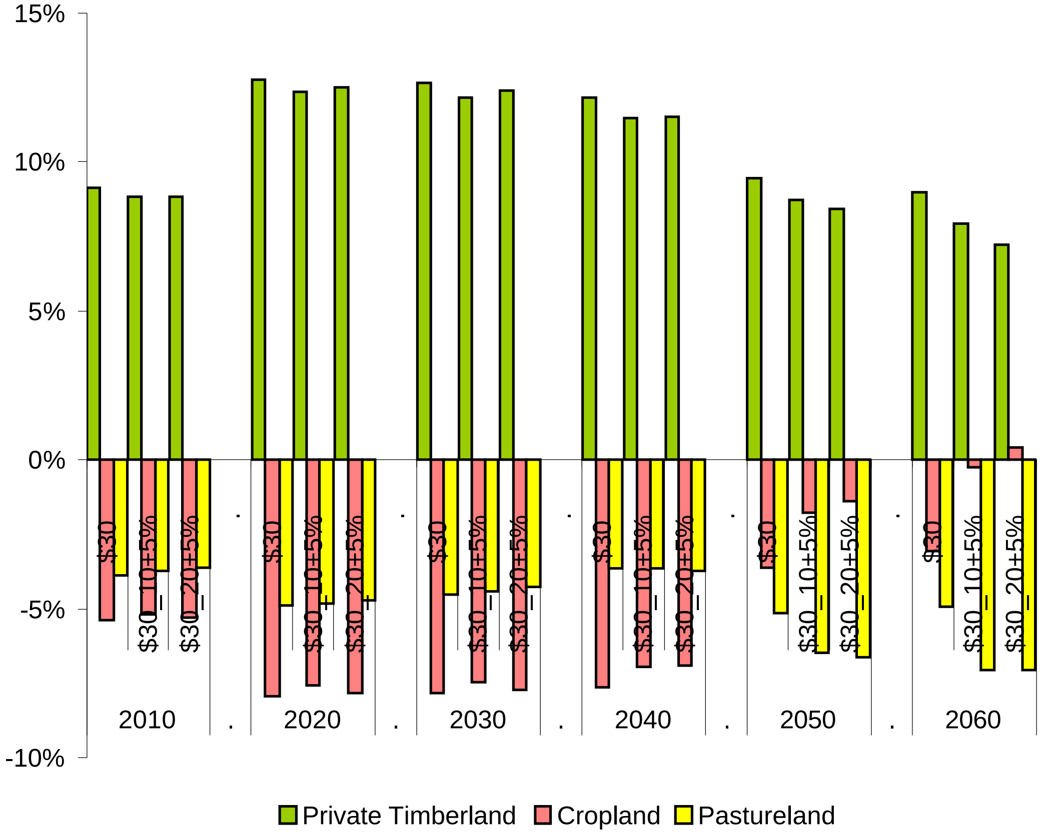


Figure 9. Percentage Land Use Change Relative to Baseline, Offset Price of $30/tCO2e



In addition to modeling effects of differing allowance and offset prices on GHG mitigation, we modeled a number of different scenarios for mitigation option eligibility for carbon payments. Under the full eligibility scenario, the forest and agricultural sectors can potentially provide 200 to 1000 Mt CO_2e of mitigation annually for constant prices of $15 to 50/t$CO_2$e, as shown in Figure 10. The majority of GHG mitigation provided by these sectors is from forest management and afforestation. There is some mitigation from bioenergy production, but it is small. This is largely due to the volume of biofuels entering in the baseline, which limits mitigation potential.

Figure 10. GHG Mitigation Potential with Full Eligibility of Mitigation Options at Different Carbon Prices

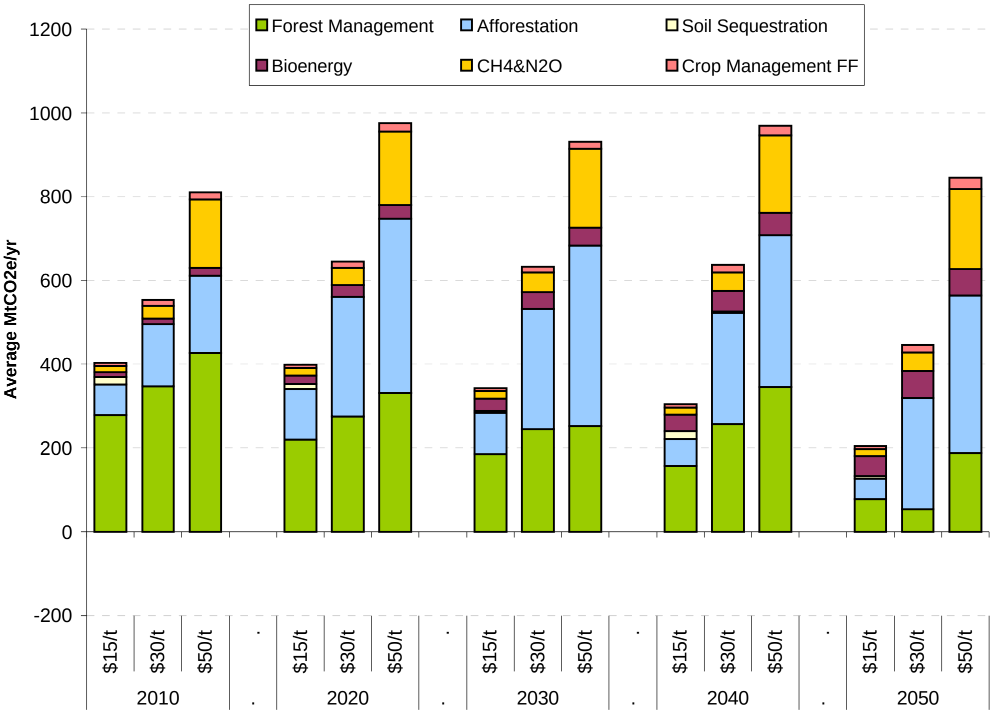
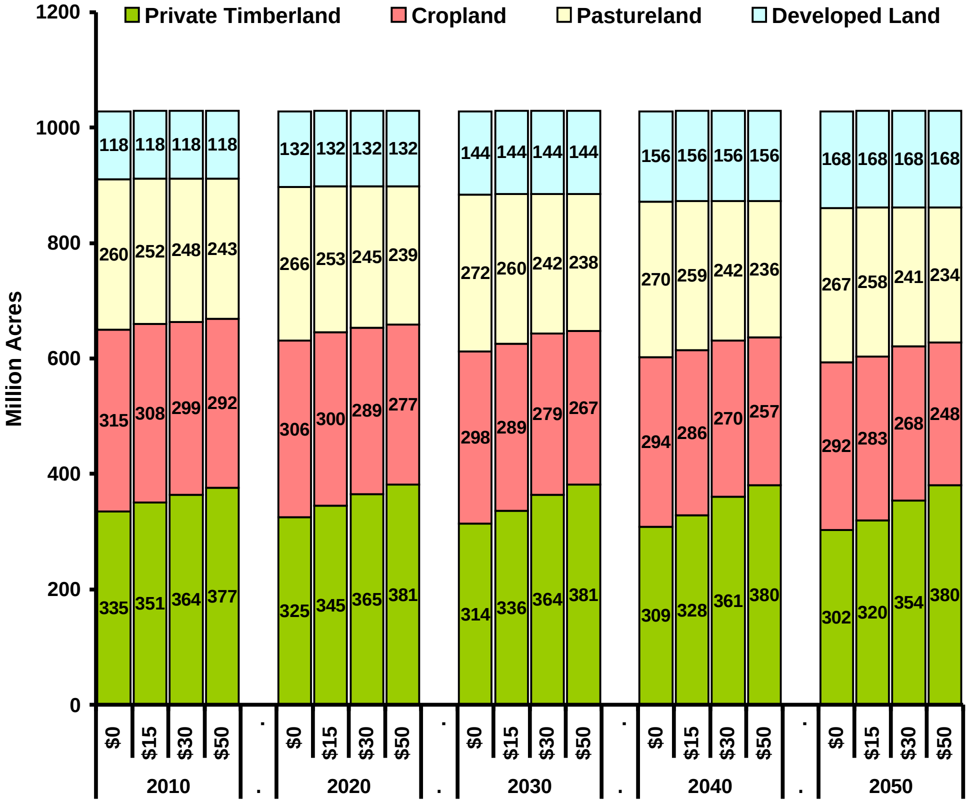


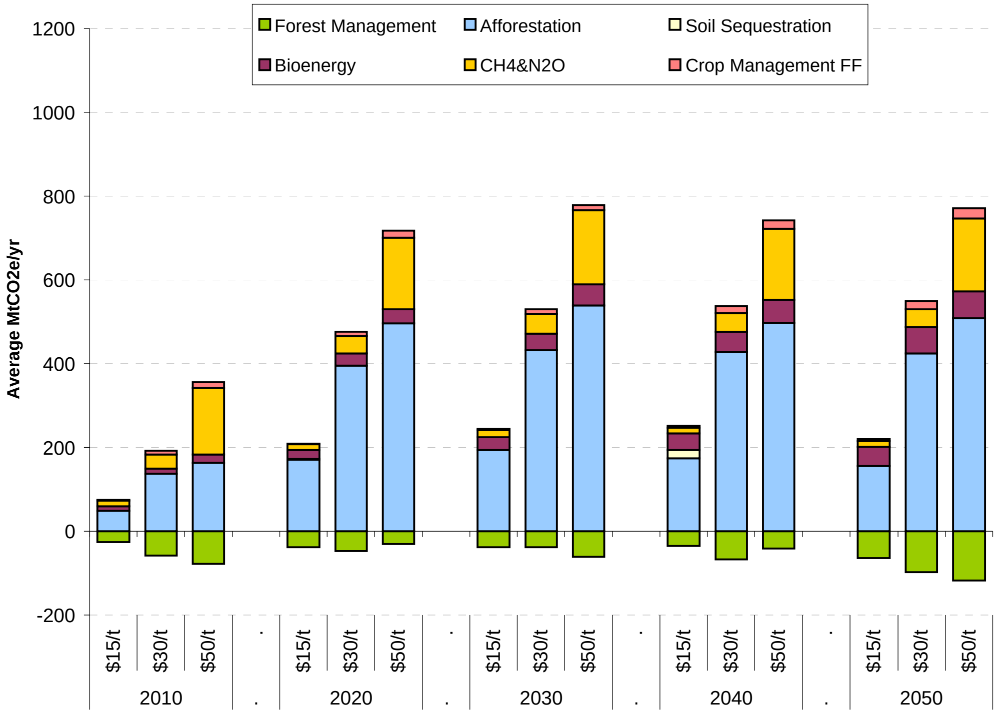
Figure 11 shows land use at alternative carbon prices over time under the full eligibility scenarios. Carbon prices results in major land reallocation from agriculture to forests, with the shift of land into forests increasing with carbon price. By 2050, private timberland area is 26 percent larger with a carbon price of $50/t$CO_2$e than in the baseline, while cropland and pasture areas are reduced by 15 percent and 12 percent, respectively.

Figure 11. Land Use with Full Eligibility of Mitigation Options at Different Carbon Prices



For the limited eligibility options, total net mitigation available at $50/tCO$_2$e declines to an average of about 600 Mt/year (see Figure 12). In addition, the majority of emissions reductions are now derived from afforestation and manure management (the two eligible offset categories in these scenarios), as expected. Forest management goes from being a large sink under full eligibility to a source as there are now incentives to convert existing forests to cropland and pasture and afforest existing agricultural lands.

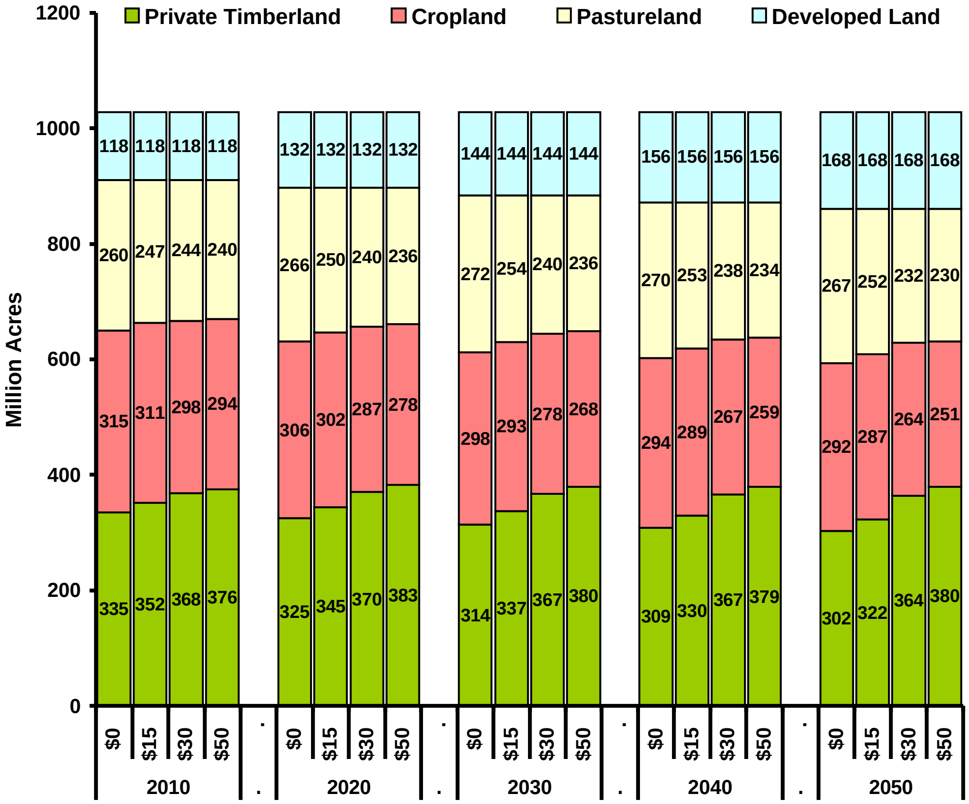
Figure 12. GHG Mitigation Potential with Limited Eligibility of Mitigation Options



Note: Under the limited eligibility scenario, only afforestation and manure management are eligible offsets. Options that would fall under capped sectors (bioenergy production and fossil fuel use in agricultural production) also receive carbon payments.

As shown in Figure 13, land use under the limited eligibility options is much more similar to the full eligibility scenario than for GHG mitigation. There is a slightly larger increase in private timberland and smaller decrease for cropland while pasture area declines more than the full eligibility case.

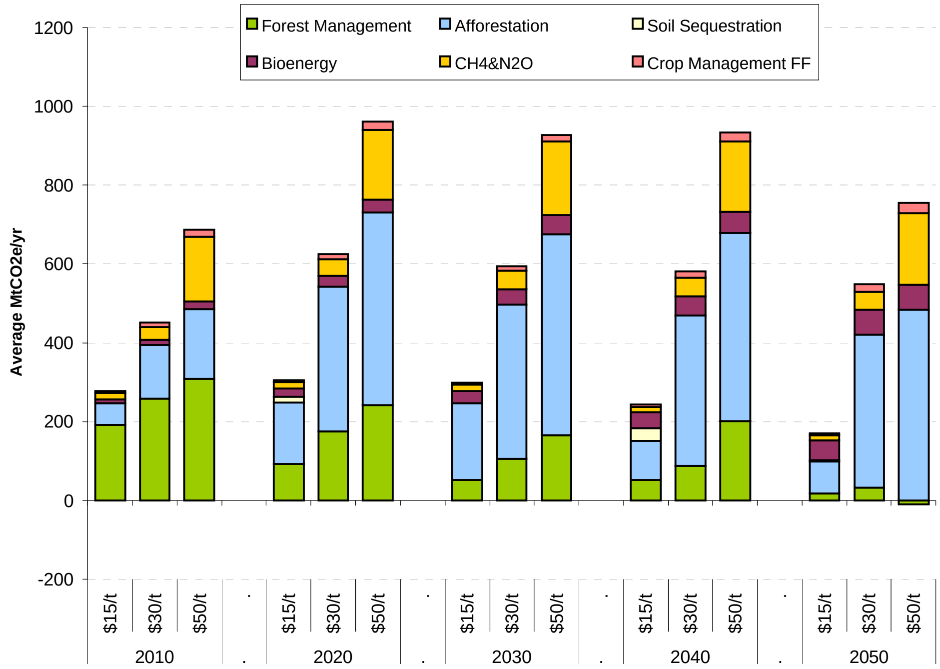
Figure 13. Land Use with Limited Eligibility of Mitigation Options



As expected, the results of the discounted eligibility scenarios generally fall between the full and limited eligibility cases. Net GHG mitigation now averages around 800 Mt/year at $50/tCO$_2$e (see Figure 14). The mix of mitigation options is similar to the full eligibility case, but with less mitigation from forest management. Although forest management is an important mitigation option under discounted eligibility, its magnitude is clearly reduced relative to the full eligibility case because landowner incentives for modifying their forest management have been reduced.

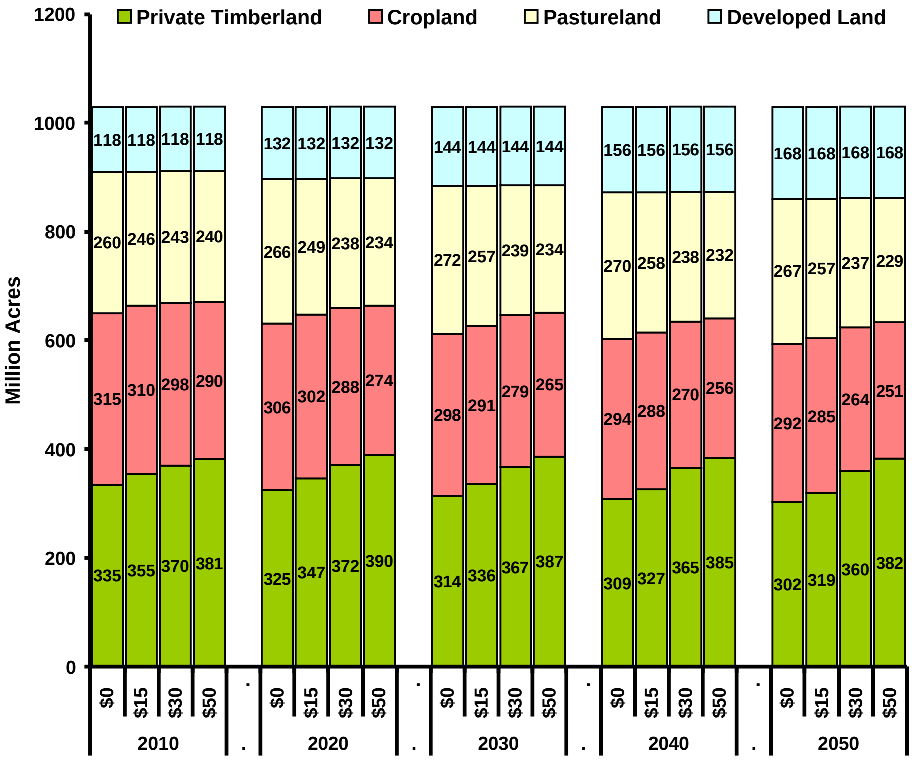
As shown in Figure 15, land use under the discounted eligibility options is similar to the previous two scenarios, but there are additional reductions in pasture relative to cropland under this set of model results.

Figure 14. GHG Mitigation Potential with Discounted Eligibility of Mitigation Options



Note: Under the discounted eligibility scenario, only afforestation and manure management are offsets credited at the full carbon price. Other offsets are credited at 50% of the full carbon price. Options that would fall under capped sectors (bioenergy production and fossil fuel use in agricultural production) also receive full carbon payments.

Figure 15. Land Use with Discounted Eligibility of Mitigation Options



Figures 16 and 17 present annualized equivalent estimates of net GHG mitigation between 2010-2050 (using a discount rate of 4 percent) for scenarios with limited and discounted mitigation options, respectively, and comparing cases where either forestry mitigation options, agricultural mitigation options, both, or neither are excluded or discounted. Forestry options provide the majority of the mitigation from these sectors in all cases where they are included. Limited eligibility across both forest and agricultural options reduces total annualized mitigation by 38 to 62 percent, whereas excluding all forestry offsets but including all agricultural offsets reduces mitigation potential by an even larger amount of 77 to 90 percent. Excluding only agricultural offsets while including forestry offsets, on the other hand, results in a range of net GHG changes between a 7 percent increase in mitigation and a 9 percent decrease across carbon prices considered. For the discounted eligibility results, mitigation potential remains relatively high with the largest reductions in mitigation potential occurring when forestry offsets are discounted and agricultural offsets are not. That case results in a 37 to 44 percent reduction in mitigation potential, as shown in Figure 17.

Figure 16. Annualized Mitigation Potential with Limited Eligibility, 2010-2040

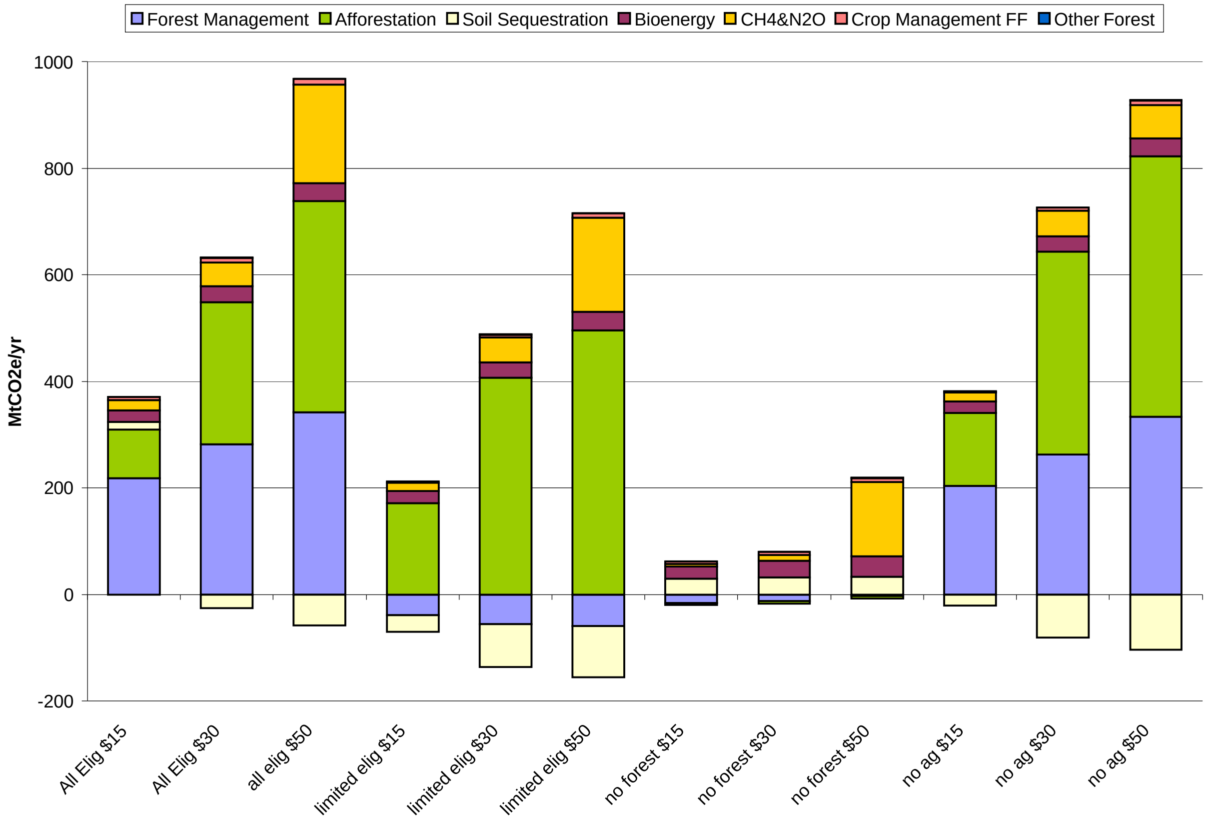
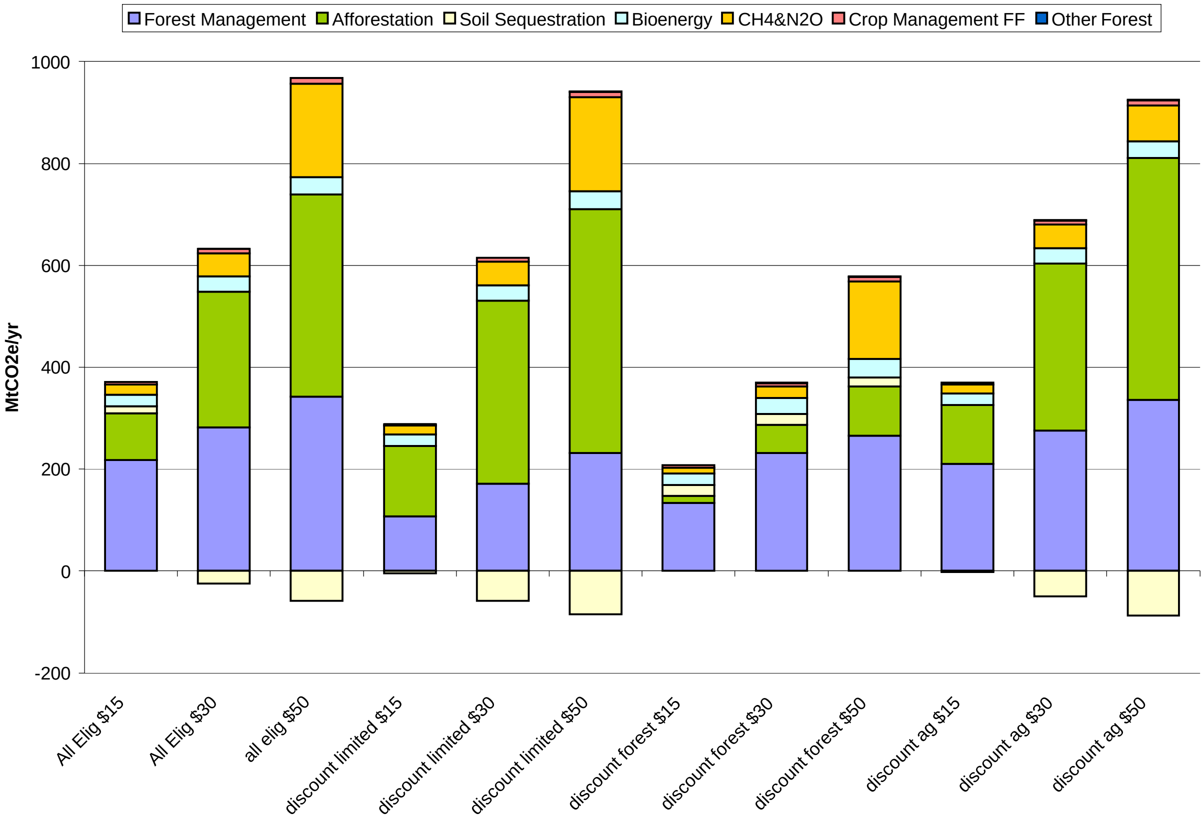


Figure 17. Annualized Mitigation Potential with Discounted Eligibility, 2010-2040



One of the striking results is the large quantity of mitigation available from forest management across our scenarios. Higher carbon prices induce greater changes in average forest management intensity and longer rotations, which is consistent with expectations as landowners modify practices to increase carbon sequestration. Figures 18 and 19 show examples of these changes in forest management activities at different carbon prices. As noted above, carbon payments can significantly increase timberland in the conterminous U.S. in almost every scenario examined. The one exception is when the forest sector is completely prevented from receiving offset credits. Otherwise, even scenarios that discount all forestry offsets by 50 percent are resulting in substantial increases in timberland relative to the baseline.

Figure 18. Change in Average Forest Management Intensity

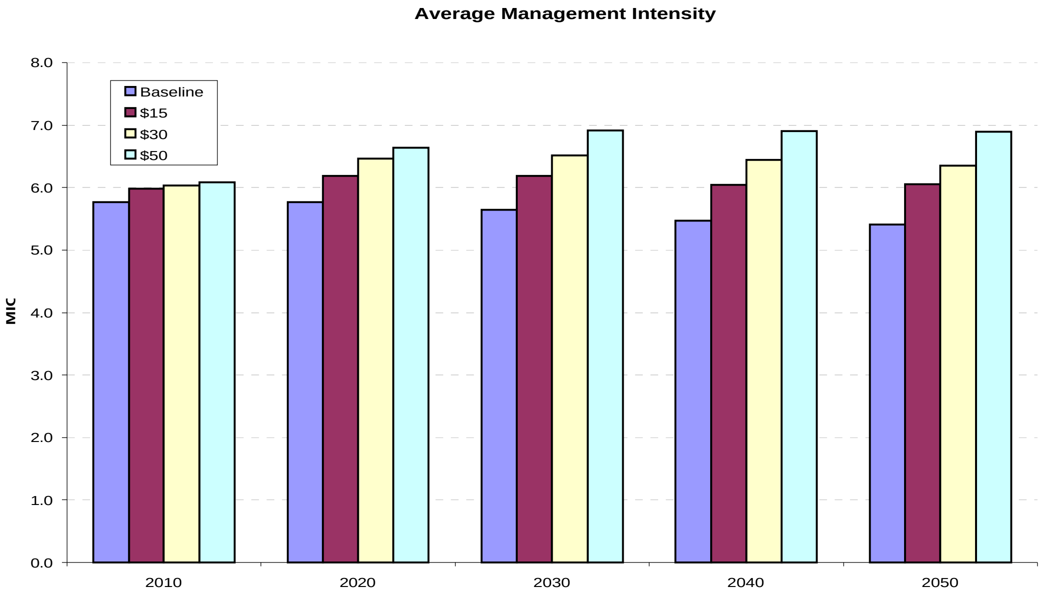
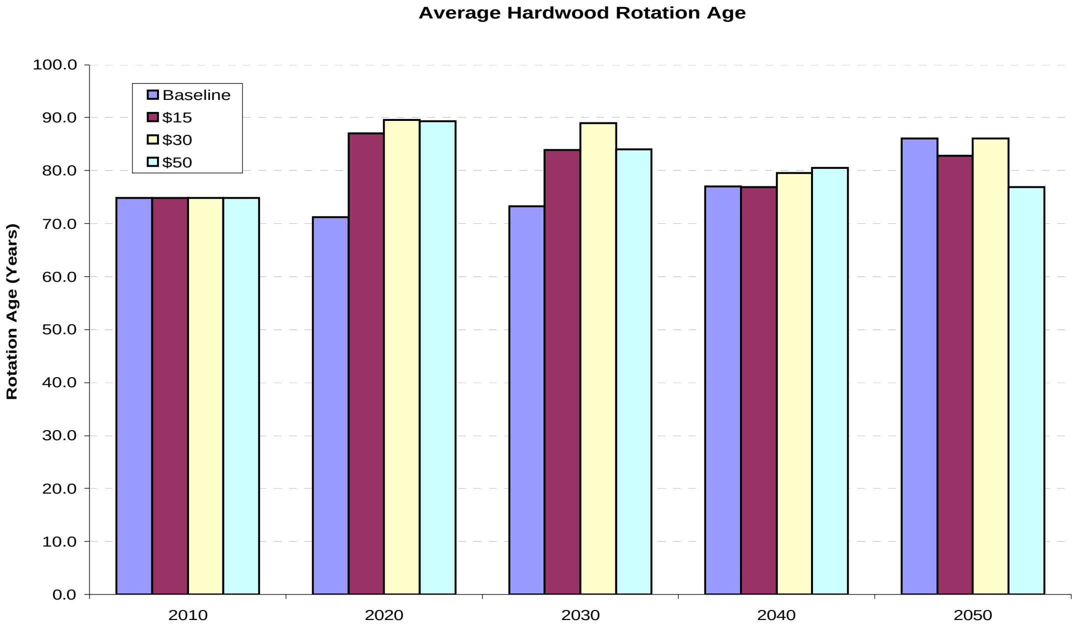


Figure 19. Change in Average Hardwood Rotation Age



6. CONCLUSIONS

There has been growing interest in climate policy in recent years and the mitigation role forestry and agricultural sectors can play in containing costs and providing opportunities for more stringent climate management. In this study, we apply one of the most comprehensive U.S. forestry, agriculture, and land use models available to explore the implications of alternative GHG mitigation policy design. Our preliminary results suggest that forestry and agriculture could provide mitigation of 200 – 1000 Mt CO_2e/year at prices of \$15 to \$50/tCO_2e. However, constraining opportunities for reducing emissions by limiting sources, regions, or practices eligible for offsets or placing a cap on offsets will increase total costs of hitting a given mitigation target. We also show that differences in relative prices for allowances (which are applied to mitigation from bioenergy and agricultural fossil fuel use in this study) and offsets could substantially affect the distribution of mitigation across options as well as total mitigation potential at a given carbon price. Although the EISA requirements for 36 billion gallons of renewable fuels by 2022 increased baseline bioenergy production in FASOMGHG and reduced mitigation potential for bioenergy relative to that higher baseline level of use, higher prices for allowances relative to offsets over time could lead to an increasingly large role for bioenergy in the mitigation portfolio in future decades.

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