**U.S. Agriculture and Forestry Greenhouse Mitigation Over Time**

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## INTRODUCTION

The Intergovernmental Panel on Climate Change (IPCC) asserts the Earth's temperature rose by approximately 0.6 $^{o}$C (1$^{o}$ F) during the 20$^{th}$ century (Houghton et al., 2001) and projects that temperature will continue to rise projecting an increase of 1.4 to 5.8$^{o}$C by 2100 (McCarthy et al., 2001). The IPCC also asserts that anthropogenic greenhouse gas emissions (GHGE) have been the dominant causal factor (Houghton et al., 2001). In response to these and other findings society is actively considering options to reduce GHGE. In 1992, 165 nations negotiated and signed the United Nations Framework Convention on Climate Change (UNFCCC), which sets a long-term goal "to stabilize greenhouse gas (GHG) concentrations in the atmosphere at a level that would prevent dangerous human interference with the climate". Subsequently, a number of programs or policy directions have been formed that are directed toward achieving emissions reductions including the Kyoto Protocol (KP), and the U.S. Presidential level Clear Skies and Global Climate Change Initiatives (Bush, 2002).

Emission reductions can be expensive. In the United States, the majority of emissions come from fossil fuel energy related sources use with about 40% of total GHG emissions coming from each of electricity generation and petroleum usage. A large emissions reduction would require actions such as

- a large reduction in energy production and use, which could be economically disruptive,
- development and use of new technologies that reduce the net GHG emissions arising in fossil fuel usage or
- fuel switching to less GHG emissions intensive energy sources.

Such actions are widely argued to be expensive and time consuming. These arguments were used in support of the U.S. rejection of the terms of KP. Nevertheless, as manifest in the KP and the President's Clear Skies initiative (Bush, 2002), the U.S. and other countries have announced intentions to limit GHGE.

Achievement of emission reductions through technological development or fuel switching takes time. Interim strategies may need to be developed to allow emissions reductions while such developments proceed. Agricultural and forestry activities offer an opportunity to buy such time (McCarl and Schneider, 1999). Known management and land use manipulations may be employed to reduce emissions, offset fossil fuel emissions, and enhance carbon sequestration. This chapter reports on the results from a study that examined the dynamic potential for GHGE reduction development in the agricultural and forestry sectors.

## AGRICULTURAL AND FORESTRY MITIGATION POSSIBILITES

The agricultural and forestry (AF) sectors present a number of possibilities that can be employed to mitigate net GHGE additions to the atmosphere. As summarized by

McCarl and Schneider (1999, 2000), these include activities directed toward reducing emissions, enhancing sinks, and offsetting emissions.

In terms of reducing emissions the AF sectors particularly agriculture are important emitters of

- methane largely through rice cultivation, ruminant livestock enteric fermentation, and manure management
- nitrous oxide largely through nitrogen fertilizer use induced emissions, legumes, and manure,
- carbon dioxide mainly through land use change from grass lands or forests to cultivated uses. In addition, smaller levels of emissions also arise through direct fossil fuel use. Indirect emissions also arise in conjunction with the production and transport of fertilizers and other inputs as well as in product transport and processing.

In terms of enhancing sinks, ecosystems involved with the AF sectoral production are large reservoirs of carbon and exhibit large annual exchanges of carbon with the atmosphere (see Lal et al, 1998 for discussion on stock magnitude and the carbon cycle). Sink enhancement can be achieved by strategies that increase the carbon input or slow the rate of decomposition. Some such strategies involve

- Altering forest management by increasing forestry rotation ages or using added inputs like fertilization.

- Changing agricultural land management by adopting less intensive tillage methods.
- Altering crop mix using more perennials that involve lessened soil disturbance.
- Altering land use from cultivated agriculture to grasslands or forests.

In terms of offsetting emissions, AF products may be used in industrial processes offsetting the use of more emissions intensive inputs and/or providing an opportunity to recycle many emissions. The principal opportunities in this category involve the use of AF products

- To replace fossil fuel use in electricity generation.
- As inputs to processes transforming them into liquid fuels replacing fossil fuels use in transportation and other usages.

## ANALYSIS REQUIREMENTS

Several features of the above mentioned AF activities imply particular approaches that must be used in a total analysis of AF potential for participating in a GHGE mitigation program. Notable features involve dynamics, multiple GHG implications, mitigation alternative interrelatedness, co benefits, market/welfare implications, and differential offset rates.

**Dynamics**

AF activities develop over time. Sinks accumulate as long as the rate of carbon addition to an ecosystem exceeds the rate of decomposition. However, as carbon accumulates the decomposition rate rises. Eventually under a sequestration increasing altered management or land use alternative, all systems will eventually come to a new equilibrium with accumulation stopping. Furthermore, crops are annuals but trees can last for many years with 50+ year rotations common in some U.S. regions. This implies that the role of AF activities in a total GHGE mitigation environment requires attention toward dynamic rates of participation.

**Multiple GHG implications**

The AF GHGE related strategies jointly have impact on the net emissions of carbon dioxide, nitrous oxide, and methane. These three gasses have significantly different causal climate change forcing effects. Equivalency rates have been established through the global warming potential (GWP) concept as discussed in the IPCC assessment reports (IPCC, 1991, Houghton et al., 2001). To develop gas equivalency and express tradeoffs we used the IPCC's 100-year global warming potentials as suggested in Reilly et al (1999).

**Mitigation alternative interrelatedness**

AF mitigation alternatives are highly interrelated because of a number of interdependencies that characterize the AF sectors. Consider three of the principal ones

- Land Competition -- AF activities compete for a common land base and expansion of land used for forests or biofuels generally implies reduction in the land used for crops or pasture and in the agricultural production from those lands.
- Intermediate products – Many AF activities requires use of the output of other activities as intermediate inputs. This is particularly true in the case of livestock consumption of crop products.
- Product substitution – A number of AF products can be used in place of one another where for example beverages can be sweetened with sugar or corn sweetners.

The important consideration here is that modeling must be complex and involve competition for land, intermediate products, and product substitution among other factors across the AF sectors (Table 1).

**Market/welfare implications**

The U.S. encompasses a large market for most commodities produced by the AF sectors. It is also an active, sometimes dominant, player in world markets for a number of AF commodities. As such the analysis needs to consider price and quantity implications for the commodities produced as well as welfare implications for domestic and foreign producing and consuming parties.

**Co-benefits**

In addition to generating emission offsets, AF GHGE mitigation alternatives also influence the environment by for example reducing erosion, improving land quality, altering wildlife habitat, and reducing chemical runoff changing water quality (McCarl and Schneider, 1999; Plantinga and Wu, 2003; Elbakidze and McCarl, 2004). AF mitigation strategy adoption has, in prior studies, been shown to have substantial implications for producer income possibly offsetting the need for extensive farm income support as occurs under U.S. farm policy (McCarl and Schneider, 2001) along with increasing forest producer income (Shugart, Sedjo, and Sohngen, 2003). As such attention to the environmental and income distribution implications of strategy use is important.

**Differential offset rates**

AF GHGE related strategies exhibit substantially different GHG offset rates. Per unit area offset rates (e.g. tons/acre) vary by more than a factor of 10 while also having implications for complementary production. For example, tillage changes get somewhere in the neighborhood of 5/8 metric tons of carbon equivalent offsets per hectare while still producing crops. Employment of afforestation or biofuels can raise the offset rate to above 2.5 tons but loses the complementary crop production.

Economic considerations would lead one to favor activities that preserve complementary traditional crop production if offset prices are low, but would cause a switch to the higher per unit offset producing alternatives losing crop production when offset prices become high.

In addition GHG offset rates vary over time with for example West and Post (2002) reviewing evidence that tillage change induced agricultural soil sequestration ceases accumulation after the first 20 years, while Birdsey's (1992, 1995) data shows forest sequestration exhibits diminishing accumulation rates in the longer term. This implies a need to look at the optimum portfolio composition of offset strategies as influenced by offset price and time.

## MODELING

In order to investigate the time dependent role of agricultural and forest carbon sequestration as influenced by offset prices we need an analytical framework that can depict the time path of offsets from agricultural and forestry possibilities. To do this we will use the GHG version of the Forest and Agricultural Sector Optimization Model (FASOM - , Adams et al, 1996) as developed in Lee (2002) and hereafter called FASOMGHG. This model has the forest carbon accounting of the original FASOM model of Adams et al unified with a detailed representation of the possible mitigation strategies in the agricultural sector adapted from Schneider (2000) and McCarl and Schneider (2001).

FASOMGHG (Lee, 2002), is a 100 year intertemporal, price-endogenous, mathematical programming model depicting land transfers between the agricultural and forest sectors in the United States. The model solution portrays a multi-period equilibrium on a decadal basis that arises from a modeling structure that maximizes the present value of aggregated producers' and consumers' surpluses across both sectors. The results from FASOMGHG yield a dynamic simulation of prices, production, management, and consumption within these two sectors under the scenario depicted in the model data.

Several aspects of FASOMGHG merit discussion including geographic scope, product scope, land transfers, agricultural management, forest management, terminal conditions, and soil and ecosystem saturation.

<u>Geographic scope:</u> FASOMGHG divides the U.S. into 11 regions where 9 of which produce forest products and 10 of which produce agricultural products.

<u>Product scope</u>: FASOMGHG simulates the production of 50 primary crop and livestock commodities and 56 secondary or processed commodities along with 10 forestry commodities. Details on the commodity coverage can be accessed at the web site: agecon.tamu.edu/faculty/mccarl.

<u>Land Transfers</u>: Four types of land transfers are depicted. These are land transferred from (1) forestry to agriculture in period t into either the pasture or cropland categories; (2) agriculture to forestry in period t from either the pasture or cropland categories; (3) cropland transferred to pasture; and (4) pasture land

transferred to cropland. Many forested tracts are not suitable for agriculture due to topography, climate, soil quality, or other factors so the model accounts for land that is not mobile between uses. Costs for converting forestland reflect differences in site preparation costs because of stump removal amounts, land grading, and other factors.

Agricultural management: The agricultural component depicts typical annual crop, livestock, processing, consumption and trade activity during a decade. Agricultural yields and factor usage vary by decade with historical trends in yield growth and input/yield interrelationships extrapolated (Chang et al 1992). Agricultural output is produced using land, labor, grazing, and irrigation water accounted for at the regional level among other inputs. Once commodities enter the market they can go to livestock use, feed mixing, processing, domestic consumption, or export. Imports are also represented. The model structure incorporates the ASM model described by Chang et al (1992) with Schneider's (2000) added GHG features. Demand and supply components are updated between decades by means of projected growth rates in yield, input usage, domestic demand, exports, and imports. The model uses constant elasticity functions to represent domestic and export demand as well as factor and import supplies. In the first two decades, the production solution is required to be within a convex combination of historical crop mixes, following McCarl (1982) and

Onal and McCarl (1991), but is free thereafter. Possibilities for greenhouse gas management are included by incorporating

- 3 tillage possibilities for cropping
- 3 alternative fertilization levels for each crop
- livestock management possibilities for feeding based on Johnson et al (2003a,b)
- manure management possibilities using digesters and methane recovery.

Forest management: The basic form of the forest sector model is a "model II" even-aged harvest scheduling structure (Johnson and Scheurman, 1977) allowing multiple harvest age possibilities. Multiple-decade forest production processes are represented by periodic regional timber yields from the Aggregate Timber Land Analysis System (ATLAS - Mills and Kincaid, 1992). Logs are differentiated into three product classes (sawlogs, pulpwood, and fuelwood) for both hardwoods and softwoods, yielding six classes in total. Substitution is permitted between sawlogs and pulpwood, pulpwood and fuelwood, and between residues generated in sawlog processing and pulpwood. Upon harvest forestlands may be regenerated into forestry with possible improvements in management, or may migrate into agriculture. Forested land is differentiated by region, ownership class, age cohort of trees, forest cover type, site productivity class, timber management regime, and suitability of forestland for agriculture use.

Terminal conditions: Given the model is defined for a finite period there will be immature trees at the end. Terminal conditions are imposed on the model that value ending immature trees and land remaining in agriculture. FASOMGHG assumes that forest management is, from the last period onward, a continuous or constant flow process with a forest inventory that is "fully regulated" on rotations equivalent to those observed in the last decades of the projection (see Adams et al. 1996). The terminal value of land remaining in agriculture is formed by assuming that the last period persists forever.

Soil and ecosystem saturation: Terrestrial carbon sinks accumulate, but are limited by ecosystem capability in interaction with the management system. In particular, carbon only accumulates until a new equilibrium is reached under the management system. FASOMGHG assumes that when cropland tillage practice or land use (to pasture or grasslands) is altered, the carbon gain/loss stops after the first 30 years based on the previous tillage studies (West and Post, 2002) and opinions of soil scientists (Parton, 2001). On the forest side carbon accounting is based on the FORCARB model as developed by Birdsey and associates (1992,1995) and the HARVCARB model of Rowe (1992). Forest carbon is accounted in four basic pools, soil, ecosystem, standing trees, and products after harvest. Under afforestation, soil carbon initially rises rapidly, but levels off particularly after the first rotation. The ecosystem component (carbon in small vegetation, dropped leaves, woody dentritus, etc) follows a similar pattern. The standing tree part is based in forest growth and yield tables from the Forest Service ATLAS model (Mills and Kincaid, 1992). The product accounting reflects products decaying over time. Thus saturation occurs as stands age while harvested pools decline as products age.

## RESULTS AND IMPLICATIONS

The basic exercise in this chapter is to examine the mitigation strategies and associated land use/land management changes that arise in agriculture and forestry under different carbon dioxide equivalent (CO2E) prices. The CO2E price is applied to $CO_2$, $CH_4$, and $N_2O$ emissions/offsets after multiplying each quantity times the relevant GWP from the IPCC (Houghton et al, 1996) report. FASOMGHG is used to simulate the strategies chosen at CO2E price incentives that are constant over time ranging from $0 to $50 per metric ton of carbon dioxide equivalent. Offset estimates are computed on a total U.S. basis relative to responses under a business as usual-zero carbon price-baseline scenario and are thus only those additionally stimulated by carbon prices.

### Static Mitigation Quantity

The strategies employed vary over time. One way of looking at the strategies employed in a static setting is to compute the annuity equivalent amount. This is done by discounting the GHGE increments by major category back to the present following the suggestion in Richards (1997). We do this using a 4% discount rate. The consequent results are in Table 2 and Figure 1. A number of trends appear in these results.

- At low GHG offset prices the first options chosen are agricultural soil carbon and existing forest stand management largely in the form of longer rotations.
- At higher GHG offset prices biofuel for power plants and afforestation dominates with agricultural soil share reduced from a peak at lower prices.
- Non-$CO_2$ related strategies largely in the form of livestock and fertilization (crop management FF(fossil fuel) related emissions offsets are relatively small but rise as the GHG offset price rises.
- Liquid fuel replacement biofuels do not enter the solution.

These results basically show that at lower prices mitigation involves use of management alternatives that are highly complementary to current land uses. In such a case, the GHG offset is largely complementary to the current land use and products produced thereon. However, the per land area production rates are lower being 1/4$^{th}$ or smaller of the biofuel and afforestation activities. At higher prices, the larger per unit area offset production possibilities are adopted, but this displaces traditional production i.e. agricultural land that is afforested does not continue to grow crops. Thus, the higher price is needed to offset the value of the crops.

In addition, the biofuel result shows the dominance of power plant usage instead of liquid fuel production largely because the power plant replacement uses little energy in production relative to the offset quantity but the liquid fuel biofuel replacement uses substantially more.

**Dynamic GHGE Mitigation**

One can look at the results as they mature over time. Figure 2-4 present accumulated GHGE mitigation credits from forest sequestration, agricultural soil sequestration, powerplant feedstock biofuel offsets, and non-$CO_2$ strategies as they vary over time for selected GHG offset prices.

At low prices and in the near term, the carbon stock on agricultural soil and in existing forests grows rapidly initially and are the dominant strategies. However, the offset quantity in these categories later diminishes and becomes stable with meaningful accumulation ceasing after about 30 years. Carbon stocks from the afforestation component of the forest sector grow for about 40 years at low prices. Non-$CO_2$ strategies continually grow throughout the whole time period. Biofuel is not a factor in the near term as it is too expensive to be part of a low carbon price mitigation plan.

When the prices are higher, the forest carbon stock increases first then diminishes; the agricultural soil carbon stock is much less important in the big picture especially in the later decades; and non-$CO_2$ mitigation credit grows over time but is not a very large player. Powerplant feedstock biofuel potential grows dramatically (ethanol is not used) over time and becomes the dominant strategy in the later decades.

Across these and other runs several patterns emerge.

- Carbon sequestration, including agricultural soil and forest carbon sequestration, and powerplant feedstock biofuel offsets are the high quantity mitigation strategies across all the results. The importance of these strategies varies by price and time.
- At low prices and in early periods agricultural soil carbon and existing forest management are the dominant strategies. When prices get higher the agricultural soil component is replaced by afforestation and powerplant feedstock biofuels as they have higher per acre carbon production rates.
- The sequestration activities tend to rise then stabilize largely due to ecosystem holding capacity. Agricultural soil accumulation stops faster than that for trees but in the longer run tree harvest begins and afforestation accumulation levels out.
- The higher the price the more carbon stored in the forests in the early decades, but the intensified forest sequestration comes with a price in that $CO_2$ emissions from forests increase later. When the forest carbon sequestration program starts, reforestation or afforestation is encouraged and the harvest of existing timber is slowed down. However, the future harvest increases because of the increased mature forests by the increasing inventory of reforestation, afforestation, and previous postponed harvests.

**Regional Effects**

Because the U.S. landscape is quite heterogeneous, the adoption and effectiveness of GHGE mitigating activities will not be uniform across regions within the country. The regional totals distribution for the price scenarios ($5, $15, and $30/ton $CO_2$) are illustrated in Figure 5. This figure summarizes the annualized GHGE mitigation quantities by major region, activity, and price scenario.

The regions with the highest GHGE mitigation fall in the South-Central, Corn Belt, and Southeast regions of the U.S. At lower GHG prices, the Lake States and Great Plains are key contributors as well. The contributions of the Corn Belt, Lake States, and Great Plains are primarily in the form of agricultural soil carbon sequestration, whereas the South-Central and Southeast regions are primarily suppliers of carbon sequestration from afforestation and forest management.

The Rockies, Southwest, and Pacific Coast Regions generate relatively small shares of the national mitigation total in all price scenarios. From those regions, only forest management from Western Oregon and Washington (PNWW) produces appreciable mitigation. This can be attributed primarily to the fact that climate and topography significantly limit the movement of land between major uses such as forestry and agriculture in the western regions.

Biofuel production occurs primarily in the Northeast, South, Corn Belt, and Lake States.

Table 3 presents a top 10 ranking by GHGE mitigation quantity of region–activity combinations. At the lowest two prices, the top-ranked combination is forest management in the South-Central region, followed by agricultural soil carbon sequestration in the Corn Belt and Lake States. As prices rise, so does afforestation in the South-Central and Corn Belt regions and biofuel production in the Corn Belt, South, and Northeast. Both the magnitude of the GHG response and the portfolio of strategies undertaken vary substantially as GHG prices rise.

**Market Effects and Co-benefits**

The introduction of the GHG offset prices causes changes in land use, tillage, fertilization, crop mix and other management practices, commodity production and consumption, and trade flows. In turn, this causes changes in market conditions and environmental loadings.

Market related results found include:

- Decline in production of traditional agricultural commodities
- Rise in agricultural and short term forest commodity prices
- Losses in consumer welfare due to higher prices
- Gains in producer welfare due to higher food prices and GHG related offset payments
- Losses in export earnings.

On the environmental side, the environmental impacts include:

- A drop in the amount of traditionally cropped agricultural land.
- A drop in irrigated area
- An increase in forested land
- An increase in biofuel land.
- A decline in loadings for nitrogen, phosphorous, and soil erosion

An interesting result is that the loadings decline substantially at low prices but in fact rise back up at higher prices due to intensification as more and more land is diverted.

In a related study, Pattanayak et al (2004) found such changes in loadings improved national aggregate average water quality about 2 percent moving the aggregate water quality measure into the swimmable range. They found that the Northern Great Plains, Southern Great Plains, Lake States, Corn Belt, and the Delta States experienced the largest water quality improvements. They also found that nitrogen loadings into the Gulf of Mexico decreased by about 9 percent.

## CONCLUSIONS

This study conducted a modeling analysis regarding the optimal portfolio of agricultural and forest sector GHGE mitigation strategies in response to alternative greenhouse gas offset prices. Focus is placed on the role of land use and land management alternatives within the portfolio in general and over time. Market and co-benefit effects are also discussed.

Our results show that the agricultural and forest sectors offer substantial potential to mitigate GHG emissions amounting to a share at high prices that could have met in the short run the magnitude of the suggested U.S. Kyoto Accord commitment. The optimal mitigation portfolio to achieve such offsets changes dynamically depending on price and time. Tillage based agricultural soil carbon sequestration and rotation length induced forest stand sequestration are the primary mitigation strategies implemented in the early decades and at low prices (below $10 per ton $CO_2$) but then accumulation ceases as ecosystem capacity is reached and or forest harvest begins. These items even turn into sources after 40 to 60 years. On the other hand, power plant feedstock biofuel activities and afforestation become more important in the longer run or at higher prices. Crop and livestock management are small but steady contributors across the entire spectrum of prices and time periods.

The findings of this study support the argument that agricultural and forest carbon sequestration provides more time to find long-run solutions such as new technologies to halt the increasing ambient greenhouse gas concentration as discussed in Marland, McCarl and Schneider (2001). It also shows that power plant feedstock biofuels are likely to be an important long run strategy under high GHG offset prices.

The co-benefits and market results show that pursuit of such strategies can have positive effects on farm incomes and on environmental quality. Many of the practices employed reduce chemical and erosion related runoff.

In terms of the overall theme of this book this chapter makes several contributions. Namely it shows

- The way that land use change and management might contribute to a societal wide effort to mitigate climate change in the near and longer terms.
- The way land use based modeling may be used to address such questions.
- A perspective of how mitigation may be pursued in a land rich country like the United States.

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Table 1. Mitigation Strategies in FASOMGHG

| | | Greenhouse gas affected | | |
|---|---|---|---|---|
| Mitigation strategy | Strategy Nature | CO2 | CH4 | N2O |
| Afforestation | Sequestration | X | | |
| Rotation length | Sequestration | X | | |
| Timberland management | Sequestration | X | | |
| Defforestation (avoided) | Sequestration | X | | |
| Biofuel production | Offset | X | X | X |
| Crop mix alteration | Emission, Sequestration | X | | X |
| Rice acreage reduction | Emission | | X | |
| Crop fertilizer rate reduction | Emission | X | | X |
| Other crop input alteration | Emission | X | | |
| Crop tillage alteration | Sequestration | X | | |
| Grassland conversion | Sequestration | X | | |
| Irrigated /dry land conversion | Emission | X | | X |
| Livestock management | Emission | | X | |
| Livestock herd size alteration | Emission | | X | X |
| Livestock system change | Emission | | X | X |
| Liquid manure management | Emission | | X | X |

Table 2: Emission Reductions in MMT of $CO_2$ Equivalent

| | Price in \$ per ton $CO_2$ Equivalent | | | | |
|---|---|---|---|---|---|
| | 5 | 15 | 30 | 50 | 80 |
| Afforestation | 2 | 110 | 450 | 845 | 1264 |
| Soil Sequestration | 120 | 153 | 147 | 130 | 105 |
| Biomass Offsets | 17 | 844 | 952 | 957 | 960 |
| CH4&N2O | 13 | 34 | 65 | 107 | 159 |
| Forest Management | 106 | 216 | 313 | 385 | 442 |
| Crop Management FF | 29 | 56 | 74 | 91 | 106 |
| All Strategies | 288 | 1413 | 2001 | 2514 | 3037 |

Table 3: GHG Mitigation Quantity Ranking by Region–Activity Combination

| | | GHG Offset $CO_2$ Equivalent Price | | | | |
|---|---|---|---|---|---|---|
| Region | Activities | $1 | $5 | $15 | $30 | $50 |
| SC | Forest management | 1 | 1 | 1 | 3 | 3 |
| CB | Ag soil carbon sequestration | 2 | 2 | 4 | 7 | 10 |
| LS | Ag soil carbon sequestration | 3 | 3 | 6 | | |
| GP | Ag soil carbon sequestration | 4 | 5 | 7 | | |
| SW | Reduce crop Fossil fuel use | 5 | 7 | | | |
| RM | Ag soil carbon sequestration | 6 | 8 | | | |
| SC | Reduce crop Fossil fuel use | 7 | 6 | 8 | 10 | |
| NE | Ag soil carbon sequestration | 8 | 9 | | | |
| CB | Reduce crop Fossil fuel use | 9 | 10 | | | |
| CB | Ag $CH_4$ and $N_2O$ mitigation | 10 | | | | |
| SE | Forest management | | 4 | 3 | 6 | 8 |
| SC | Afforestation | | | 2 | 1 | 2 |
| NE | Biofuel offsets | | | 5 | 4 | 5 |
| RM | Afforestation | | | 9 | | |
| SW | Ag soil carbon sequestration | | | 10 | | |
| CB | Afforestation | | | | 2 | 1 |
| SE | Biofuel offsets | | | | 5 | 4 |
| SC | Biofuel offsets | | | | 8 | 6 |
| CB | Biofuel offsets | | | | 9 | 7 |
| LS | Afforestation | | | | | 9 |

Notes:
CB is Corn Belt and included states in vicinity of Illinois.
GP is Great Plains and includes states in vicinity of Nebraska.
LS is Lake States and includes states in vicinity of Michigan.
NE is North East and includes states in vicinity of New York.
RM is Rocky Mountains and includes states in vicinity of Colorado.
SC is South Central and includes states in the vicinity of Mississippi.
SC is South East and includes states in the vicinity of Georgia.
SW is South West and includes states in vicinity of Texas.

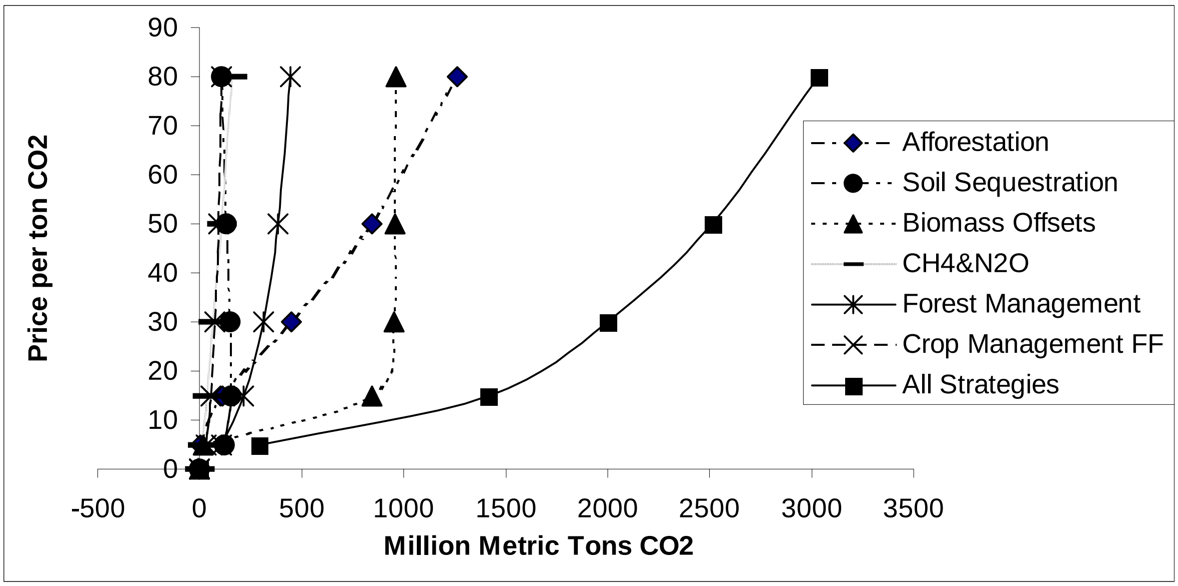


Figure 1. Annualized Mitigation Potentials of Chosen Mitigation Tools at Different GHG Offset Prices

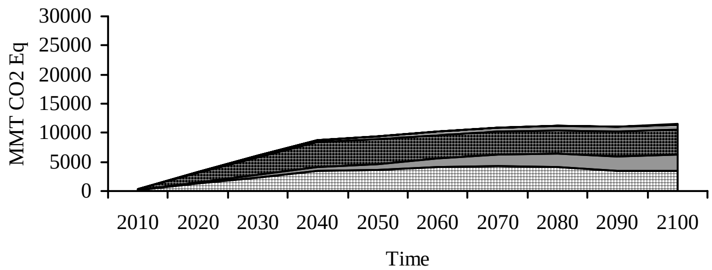


Figure 2. Cumulative Mitigation Contributions from Major Strategies at a $5 $CO_2$ Equivalent Price

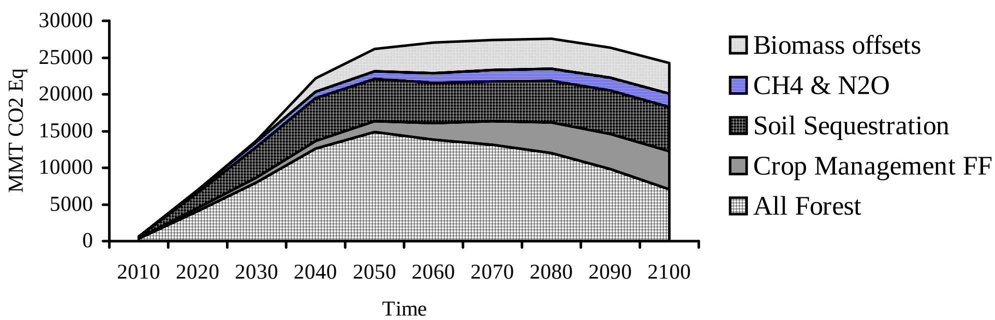


Figure 3. Cumulative mitigation contributions from major strategies at a $15 $CO_2$ Equivalent Price

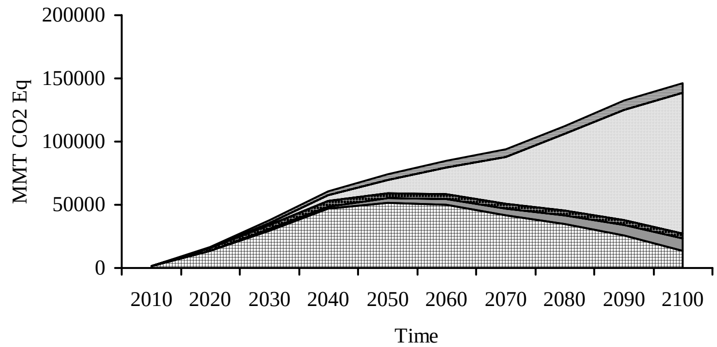


Figure 4. Cumulative Mitigation Contributions from Major Strategies at a $50 $CO_2$ Equivalent Price

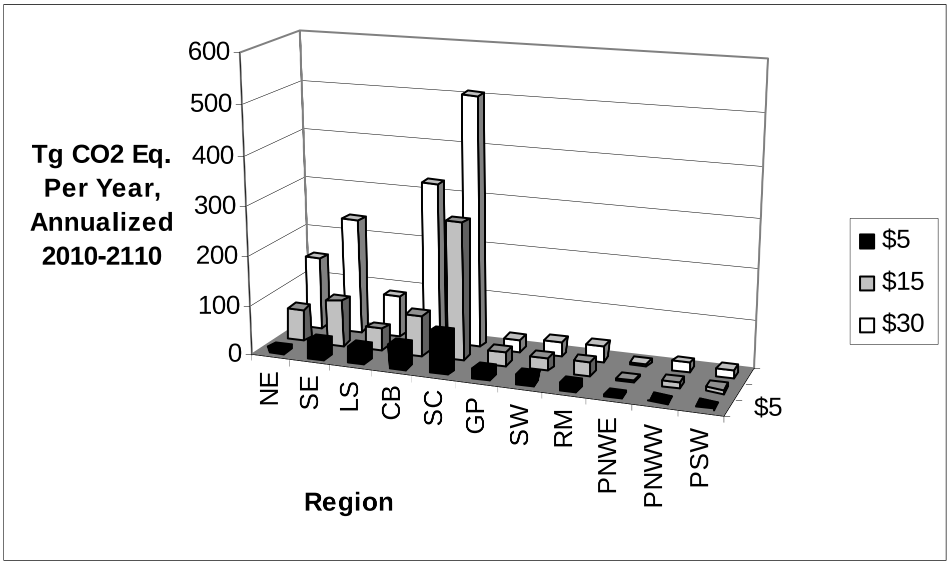


Figure 5 Annualized Total Forest and Agriculture GHGE Mitigation by Region at three GHGE prices

Notes:
CB is Corn Belt and included states in vicinity of Illinois.
GP is Great Plains and includes states in vicinity of Nebraska.
LS is Lake States and includes states in vicinity of Michigan.
NE is North East and includes states in vicinity of New York.
PNWE is Pacific Northwest East Side -- the eastern parts of Washington and Oregon.
PNWW is Pacific Northwest West Side -- the western parts of Washington and Oregon.
PSW is Pacific Southwest and is in the state of California.
PSW is Pacific Southwest and is in the state of California.
RM is Rocky Mountains and includes states in vicinity of Colorado.
SC is South Central and includes states in the vicinity of Mississippi.
SC is South East and includes states in the vicinity of Georgia.
SW is South West and includes states in vicinity of Texas.