Greenhouse Gas Mitigation Potential in U.S. Forestry and Agriculture

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Chapters 5 - 8

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CHAPTER 5

Mitigation Potential of Selected Activities

Chapter 5 Summary

GHG mitigation for forestry and agriculture is considered on a more limited scale than the comprehensive coverage assessed in Chapter 4. Scenarios include fixed time-specific (Year 2025 and Year 2055) GHG mitigation quantities from forestry and agriculture, payments for CO_2 only (vs. for all GHGs), and payments for selected mitigation activities.

For fixed time-specific scenarios, the effectiveness of GHG mitigation depends on the size of the fixed mitigation quantity and whether efforts to maintain that level of mitigation remain in place or expire. Aiming for future annual mitigation levels could lead to unintended GHG releases in preceding years. This is particularly relevant for forest carbon. Aiming for cumulative, rather than annual, mitigation could address this problem.

Paying for CO_2 mitigation only does not significantly diminish the net GHG mitigation potential of forestry and agriculture compared to scenarios where payments for all GHGs are made, since most GHG mitigation occurs through sequestration and CO_2 reductions. Non-CO_2 reductions prove to be complementary to—and thus occur with—CO_2 mitigation.

Scenarios in which only agricultural activities are carried out can achieve moderate levels of GHG mitigation, even at fairly low cost. Forest carbon sequestration and biofuels contribute more substantially at somewhat higher price scenarios or when price scenarios rise over time. Agricultural GHG mitigation opportunities are widely distributed across the United States, but most forest GHG mitigation opportunities occur in the South.

The previous chapter evaluated GHG mitigation potential under scenarios for all three critical GHGs (CO_2, CH_4, and N_2O) across all agricultural activities and carbon sequestration options in forestry and agriculture. As the results indicate, a comprehensive payment approach has the potential for large-scale mitigation, potentially generating up to 2,000 Tg CO_2 (2 billion tonnes CO_2 Eq., or about 550 Tg C Eq.) per year of mitigation.

However, for several reasons forestry and agriculture's role in national GHG mitigation might involve less than comprehensive coverage of all activities and GHGs (Sampson 2003; Richards et al. forthcoming):

- Much of the focus to date on GHG mitigation has been on emissions from energy-producing sectors, while the role of forestry and agriculture has been seen more as a cost-effective means to offset emissions from these other sectors.
- Some GHG-emitting (sequestering) activities in forestry and agriculture are difficult to measure, monitor, and verify and could thereby be difficult to include in a comprehensive accounting and incentive approach.
- Individual sources of emissions and sequestration tend to be small and widely dispersed over the landscape, making cost-effective aggregation of mitigation activities potentially difficult.

Because of these issues, it is reasonable to evaluate smaller-scale mitigation than that assessed in Chapter 4. In this case, some activities, GHGs, and locations might be subject to mitigation activities and incentives, while other activities, GHGs, and locations might not be covered. Many potential selected activity combinations or mitigation quantities are feasible. A few are reviewed here to explore the implications of limiting activities or quantities of GHG reductions or sequestration:

- setting a fixed national GHG mitigation quantity for a selected date (e.g., 375 Tg CO_2 Eq. per year in 2025),
- paying for GHG mitigation only for selected gases (e.g., CO_2 only), and
- paying for GHG mitigation only for selected activities (e.g., agricultural soil carbon only).

This chapter continues first with an analysis of several hypothetical aggregate national GHG mitigation levels for the combined forest and agriculture sectors. The fixed quantities assessment is followed by evaluations of GHG payments that are limited either in terms of the GHGs covered, the activities covered, or the prices paid. Such an approach could be similar in many ways to project-based mitigation, in which initiators of a GHG mitigation project take actions to reduce emissions or increase sequestration on site and quantify and report these net reductions.

Fixed Quantities of National GHG Mitigation

The three scenarios evaluated in this section are defined in Table 5-1. Each scenario sets a fixed level of reduced net emissions by 375 Tg CO_2 (just over 100 Tg carbon) per year below the BAU GHG baseline for the two sectors by the year 2025.

The three scenarios explore the effect of maintaining, increasing, or dropping an early, initial mitigation level in the out years. In the first case (T-375-375), the 2025 mitigation level is kept in place thereafter through the end of the projection. In the second scenario (T-375-900), the 2025 quantity is increased from 375 Tg CO_2 to 900 Tg CO_2 (250 Tg C) per year by the year 2055, remaining at that level thereafter. Under the third scenario (T-375-0), once the 2025 mitigation quantity is achieved, no aggregate quantity is specified thereafter. To put this in context, 375 Tg and 900 Tg CO_2 Eq., would respectively offset about 5 and 13 percent of the U.S. GHG emission totals for 2003 (EPA 2005).

Table 5-1: National GHG Mitigation Quantity Scenarios for 2025 and 2055

All quantities are measured in Tg CO_2 Eq. per year net emission reductions below baseline.

Quantities for 2025 and 2055 can be met by achieving average annual reductions for the representative decade (2020–2030, and 2050–2060), respectively.

Scenario	U.S. Quantity, 2025	U.S. Quantity, 2055
T-375-375	375	375
T-375-900	375	900
T-375-0	375	0

The analysis uses FASOMGHG to find the solution to the least-cost combination of activities and locations to achieve given national mitigation levels for the forest and agriculture sectors.

National-Level Results by Activity and Time Period

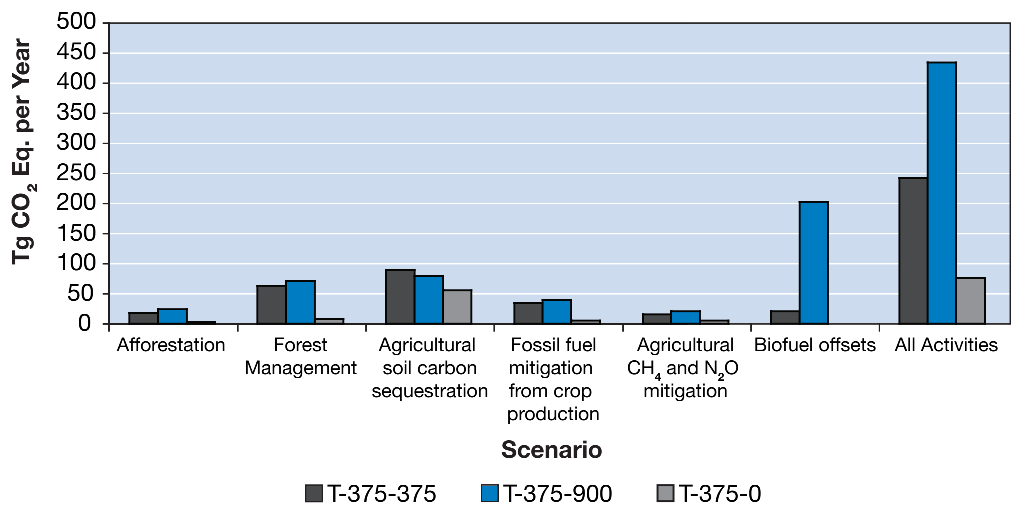
The results of the FASOMGHG simulations for the three national mitigation quantity scenarios are summarized in Table 5-2 and Figure 5-1. They present national mitigation results that are annualized for the entire 100-year projection period by activity. These results report the national-level GHG quantities and marginal cost of the activity mix that the model identifies as likely to be implemented to achieve the given GHG reduction quantity, for the target date, at least cost. Some key results are the following:

- **The scenario that fixes the national mitigation quantity at 375 Tg per year from year 2025 and beyond achieves that quantity with a broad mix of activities.** While agricultural soil carbon sequestration and forest management make the largest contribution, as in the lower-

Table 5-2: National Mitigation, by Scenario and Activity, for Least-Cost Quantity in 2025 and 2055: Annualized over 2010–2110
Quantities are Tg CO_2 Eq. per year net emissions reduction below baseline.

	Scenario: Quantities in 2025—Quantities in 2055 in Tg CO_2 per Year Above Baseline		
	T-375-375	T-375-900	T-375-0
Annualized (2010–2110)			
Afforestation	18	23	2
Forest management	62	70	9
Agricultural soil carbon sequestration	88	79	54
Fossil fuel mitigation from crop production	35	38	4
Agricultural CH_4 and N_2O mitigation	16	20	5
Biofuel offsets	21	200	0
All Activities	240	429	75
Marginal Cost per t CO_2 Eq. Year 2000 $	$23.38	$26.10	$14.76

Figure 5 1: Least Cost Mitigation Quantities by Scenario and Activity in 2025 and 2055
Quantities are Tg CO_2 Eq. per year net emissions reduction below baseline, annualized over 2010 2110.



price scenarios in Chapter 4, the other four major activities also make substantive contributions, leading to a diverse portfolio of options.

- **When the quantity is raised from 375 Tg/year in 2025 to 900 Tg/year in 2055, the role of biofuels emerges as a dominant strategy.** In this much larger level of activity emphasizing longer-term mitigation, biofuels account for almost one-half the annualized total GHG mitigation.
- **When the 375 Tg/year mitigation quantity level is completely relaxed after 2025, the policy's effectiveness is substantially undermined.** It produces less than one-third the

annualized mitigation of the constant 375 Tg quantity (T-375-375) and less than 20 percent of the T-375-900 scenario quantity.

- **Agricultural soil carbon sequestration and forest management are key options in all three scenarios.** Agricultural soil sequestration is the first or second contributing activity in all three scenarios, and forest management is second or third in all three.
- **Afforestation makes little contribution to the mitigation totals under any of the national mitigation quantity scenarios.** Although afforestation is a key strategy at the middle to upper prices in the GHG pricing scenarios of Chapter 4, the other options are more cost-effective ways to achieve the fairly modest national mitigation levels assessed here. Afforestation is an effective strategy for a more aggressive effort to achieve higher mitigation totals at higher cost per unit mitigated.
- **The marginal cost ranges from about $15 to $26 per tonne CO_2 Eq., depending on the stringency of the mitigation scenario.** The marginal cost per tonne is about the same for the scenarios where the mitigation goal stays the same or rises in the second period (to 2055) but is about half that amount for the scenario that has no goal after 2025. The marginal cost of an additional tonne of mitigation measures the net cost of an additional unit being added to the GHG mitigation quantity.[1] In essence, this suggests that additional mitigation could be warranted if the marginal benefits exceed these levels.

The summary results of Table 5-2 could mask important variations in sectoral mitigation over time. These timing patterns are illustrated in Figure 5-2, which shows cumulative mitigation totals over time under the three quantity scenarios, and in Table 5-3, which reports annual totals by activity for three key years: 2015, 2025, and 2055. The patterns demonstrate that the establishment of fixed and finite-lived mitigation levels can induce undesirable consequences before the quantity goal takes effect and after the mitigation quantity is no longer in place, as described below.

Recall that in each case, the annual mitigation quantity does not come into effect until 2025. Therefore, all action in the first decade (2010–2020) is unrestricted. As a result of this delay, two phenomena are projected. First, emissions of CO_2 and non-CO_2 gases are not much affected in the first decade, because there is no incentive to achieve these reductions until later. Second, the sequestration activities reflect anticipatory behavior. The net level of annual sequestration in 2015 is lower under the national quantity scenarios than under the baseline, as reflected by the negative values in Figure 5-2 and Table 5-3. In other words, the 2025 mitigation quantity goal induces carbon release in the preceding decade.

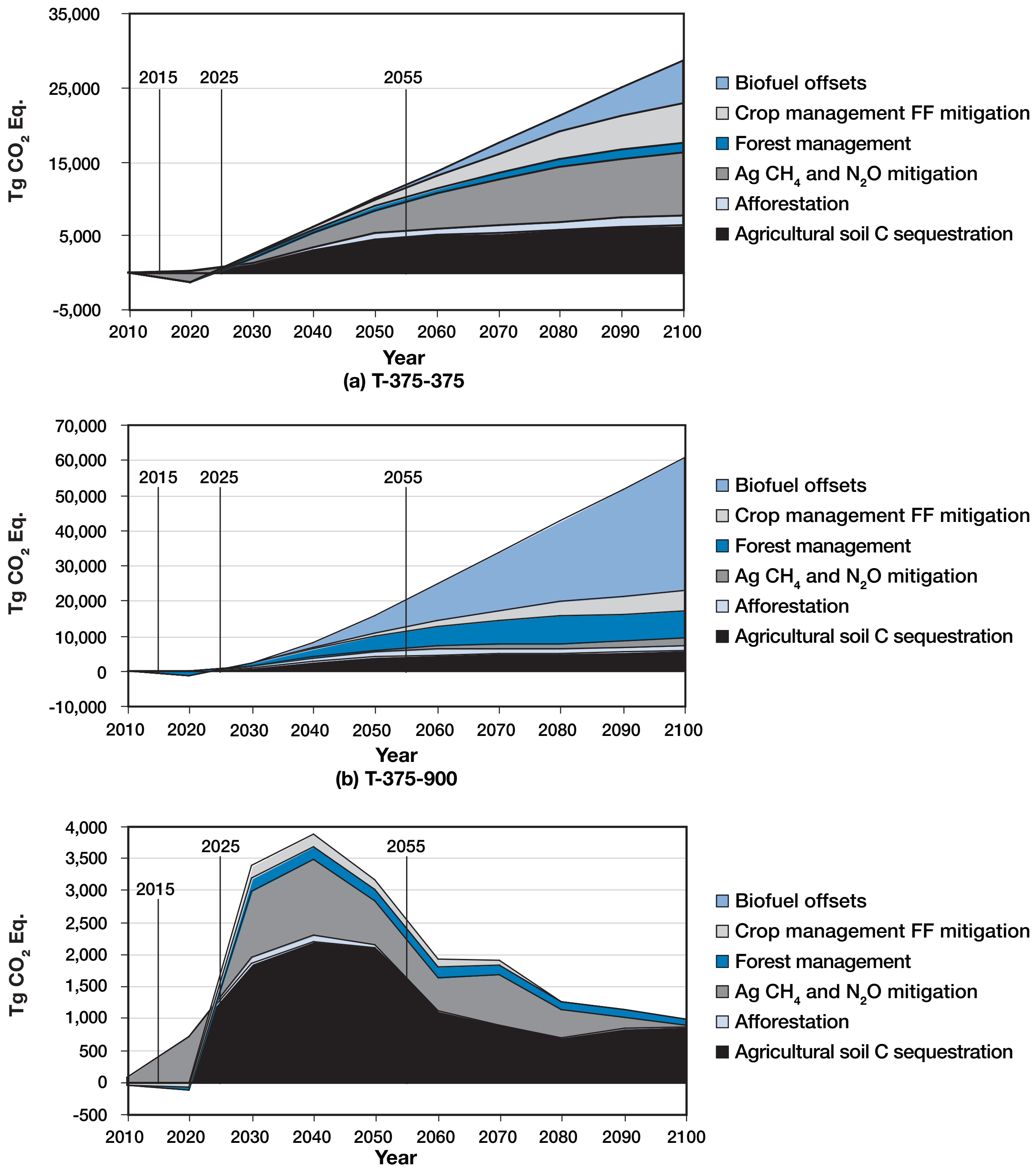
The early induced carbon releases are especially pronounced for forest management, where relatively large carbon reductions are projected in the decade preceding the mitigation quantity level taking effect in 2025. This pattern implies a reaction by forest owners to reduce carbon stocks before the target takes effect through some combination of higher harvests or reduced management. This may be a reaction to preempt some of the opportunity costs placed on harvests when the fixed levels take effect in 2025. Nonetheless, it suggests that a national mitigation quantity set to take effect a decade or more in the future could produce some short-run unintended negative consequences if not designed carefully.

The unintended consequences can extend beyond the time period as well. For the one scenario in which the national quantity level is not kept in place after 2025, net sequestration levels drop below the baseline for each of the forest and agriculture sequestration options. Without a continuing mitigation quantity to shoot for, landowners have little incentive to keep carbon stocks above baseline levels.

[1] The cost to consumers and producers is measured as the aggregate sum of producer and consumer surplus in the forest and agriculture sectors. This is commonly referred to as the "social welfare cost" of a market intervention.

Figure 5 2: Scenarios with Objective of Mitigating: (a) 375 Tg CO_2 Eq. in 2025 and Maintaining; (b) 375 in 2025 and 900 Tg CO_2 Eq. in 2055; and (c) 375 Tg CO_2 Eq. in 2025 without Maintaining Thereafter

Quantities are Tg CO_2 Eq. cumulative net emissions reduction below baseline to 2110.
Quantities are Tg CO_2 Eq. cumulative net emissions reduction below baseline to 2110.
Note: Scale varies for each graph, from 4,000 to 70,000 Tg CO_2.



(a) T-375-375

(b) T-375-900

(c) T-375-0

Table 5-3: Least-Cost Mitigation Response to Fixed National GHG Mitigation Levels in 2015, 2025, and 2055
Quantities are Tg CO_2 Eq. per year net emissions reduction below baseline.

	Scenario: Quantities in 2025—Quantities in 2055 in Tg CO_2 per Year Above Baseline		
Year	**T-375-375**	**T-375-900**	**T-375-0**
2015 (midpoint of 2010 decade)			
Afforestation	8	9	1
Forest management[a]	–180	–192	–105
Agricultural soil carbon sequestration	–6	–18	58
Fossil fuel mitigation from crop production	4	1	3
Agricultural CH_4 and N_2O mitigation	5	3	3
Biofuel offsets	0	0	0
All Activities	–170	–198	–41
2025 (midpoint of 2020 decade)			
Afforestation	17	20	9
Forest management	234	230	207
Agricultural soil carbon sequestration	87	85	124
Fossil fuel mitigation from crop production	18	19	17
Agricultural CH_4 and N_2O mitigation	19	20	17
Biofuel offsets	0	0	0
All Activities	375	375	375
2055 (midpoint of 2050 decade)			
Afforestation	3	33	–13
Forest management	161	184	–22
Agricultural soil carbon sequestration	66	51	–99
Fossil fuel mitigation from crop production	59	69	–3
Agricultural CH_4 and N_2O mitigation	20	27	–2
Biofuel offsets	66	536	0
All Activities	375	900	–139

[a] Positive values indicate mitigation or reductions in net emissions below baseline levels. Negative values indicate an increase in net emissions above baseline levels. Net emission increases are possible when the desired mitigation levels are not in effect, such as in 2015, and after 2025 under T 375-0.

Regional Activity Contributions to National Mitigation Levels

The top 10 region/activity combinations that could contribute to the national mitigation quantity scenarios are presented in Table 5-4.[2] The region-activity rankings for the $15/tonne CO_2 Eq. constant price scenario from Chapter 4 are also listed in Table 5-4 for comparison.

For the two scenarios with mitigation quantity levels continuing beyond 2025, a diverse mix of activities and regions comprises the mitigation portfolio. For the T-375-375 scenario, the top 10 opportunities are spread across eight regions and across all but one of the activities.

The regional diversity narrows some when the 2055 quantity is set at 900 Tg CO_2 per year, because

Table 5-4: GHG Mitigation Quantity Ranking by Region/Activity Combination: Fixed National Mitigation Quantity Scenarios
Quantities are Tg CO_2 Eq. per year net emissions reduction below baseline, annualized 2010–2110.

		Scenarios							
		T-375-375		T-375-900		T-375-0		Constant $15 GHG Price	
Region[a]	Activities	Rank	GHG Quantity	Rank	GHG Quantity	Rank	GHG Quantity	Rank	GHG Quantity
CB	Agricultural soil carbon sequestration	1	35.6	4	39.3	1	20.8	4	62.2
SE	Forest management	2	33.9	3	39.9	3	10.4	3	69.2
LS	Agricultural soil carbon sequestration	3	31.3	5	31.6	2	15.2	6	36.9
SC	Fossil fuel mitigation from crop production	4	17.4	7	16.9			8	23.7
NE	Biofuel offsets	5	13.8	1	121.7			5	47.9
SC	Forest management	6	12.0	8	13.5			1	127.7
RM	Afforestation	7	11.8	9	11.8			9	11.7
SW	Fossil fuel mitigation from crop production	8	8.8	10	8.8				
NE	Forest management	9	7.0						
GP	Agricultural soil carbon sequestration	10	6.8			4	6.8	7	29.3
RM	Agricultural soil carbon sequestration					5	3.8		
NE	Agricultural soil carbon sequestration					9	1.6		
SW	Agricultural soil carbon sequestration					6	3.6	10	10.5
CB	Afforestation					7	2.0		
SE	Biofuel offsets			2	49.3				
SC	Biofuel offsets			6	28.8				
RM	Agricultural CH_4 and N_2O mitigation					8	1.9		
SC	Agricultural CH_4 and N_2O mitigation					10	1.5		
SC	Afforestation							2	115.8

[a] See Table 3-2 in Chapter 3 for region key.

[2] Consult Chapter 3, Table 3-2, for a key of the regions tracked by the FASOMGHG model.

5 of the top 10 opportunities occur in the two southern regions. And agricultural soil carbon sequestration is the dominant strategy for the T-375-0 scenario, reflecting the short-term nature of the scenario. Non-CO_2 mitigation is part of the top 10 set in the T-375-0 scenario only.

National Mitigation Quantity Scenarios Summary

Taken together, the three national quantity scenarios provide insights into the importance of timing in implementing mitigation options. First, one sees that delaying *the achievement of a specific national mitigation quantity a decade or more can induce some emitting activity in the short term.* This occurs primarily with the sequestration options, where carbon stock dynamics inextricably link actions and carbon consequences across decades. Therefore, setting a future mitigation goal directly affects land use and management decisions today.

However, the early reductions in sequestration found in the model simulations occur, in part, because these particular scenarios were designed to achieve *annual* mitigation quantities, relative to a future baseline. If, instead, the scenario was set to maintain a certain level of carbon *stock* in the future and this stock was higher than the stock that exists at the time such a goal is announced, then the incentive to reduce carbon stocks prior to the scenario date would be effectively eliminated. *Aiming for cumulative rather than annual mitigation quantities could potentially avoid these early period unintended consequences.*

GHG benefits are likely to be reversed if the desired mitigation level is not maintained. But a more permanent enhancement in forest and agricultural carbon storage and emissions reduction would require a sustained commitment to achieve these levels.

Limiting Payments by GHG Type

The analyses to this point have considered all major GHGs in forestry and agriculture (CO_2, CH_4, and N_2O) to be subject to mitigation incentives. However, much of the focus in climate change mitigation has been on CO_2, whose emissions constitute a majority of the aggregate anthropogenic global warming potential, especially in the United States. Therefore, we consider the consequences of focusing incentives on emissions and sequestration of CO_2 only. This is particularly interesting for the agriculture sector, a major source of non-CO_2 emissions that could be perversely affected by a CO_2-only policy, if it led to increases in agricultural non-CO_2 GHGs.

Paying for CO_2 Only vs. Paying for All GHGs: \$15/t CO_2 Eq.

To evaluate the CO_2-only option, the FASOMGHG model was run with a price of \$15/t CO_2 Eq. for CO_2 emissions and sequestration and a price of zero for the other GHGs tracked by the model. Results of this scenario are compared to the results when all GHGs are paid \$15 per tonne CO_2 Eq. as illustrated in Table 5-5.

Table 5-5: Mitigation Quantities: Payments for CO_2 Only vs. Payment for All GHGs (\$15 per t CO_2 Eq.)
Quantities are Tg CO_2 Eq. per year net emissions reduction below baseline, annualized 2010–2110. Net emissions include non-CO_2 gases (even though payments are for CO_2 only).

Activity	CO_2 Only	All GHGs
Afforestation	110	137
Forest management	216	219
Agricultural soil carbon sequestration	176	168
Fossil fuel mitigation from crop production	49	53
Agricultural CH_4 and N_2O mitigation	21	32
Biofuel offsets	42	57
All Activities	613	667

The results in Table 5-5 represent annualized totals for the entire projection period and can be summarized as follows:

- Limiting payments to CO_2 only reduces total mitigation potential by about 54 Tg/year or about 8 percent below the mitigation obtained when all GHGs are priced.

- CO_2 and non-CO_2 mitigation are largely complementary:
  - About two-thirds of the non-CO_2 mitigation can be accomplished while paying for CO_2 only.
  - CO_2 mitigation (e.g., especially afforestation and biofuels) is enhanced when non-CO_2 gases are included in the payment approach ("all GHGs"), suggesting that non-CO_2 reduction incentives divert land from traditional agriculture to these activities.
  - Only agricultural soil carbon sequestration shows a (slight) trade-off between CO_2 and non-CO_2 payments (i.e., the amount of agricultural soil carbon sequestered declines very slightly when all GHGs are subject to payment, rather than just CO_2).

The complementarity between CO_2 and non-CO_2 mitigation is a potentially important factor when considering incentives for mitigation. First, it implies that much of the non-CO_2 mitigation can be achieved without explicitly providing incentives to reduce non-CO_2 gases. Second, it implies that including the non-CO_2 reduction activities has synergistic benefits in CO_2 reductions.

CO_2 Only: Mitigation Over Time

To illustrate mitigation over time, Table 5-6 presents the mitigation results for CO_2-only payment by activity for the key years of 2015, 2025, and 2055, and Figure 5-3 shows cumulative mitigation totals for the CO_2-only and all GHG payment options for the entire projection period.

The temporal patterns shown in Table 5-6 and Figure 5-3 reinforce results presented earlier, namely that *forest and agricultural sequestration options generate sizeable quantities of mitigation in the first couple of decades after implementation, but these effects diminish and even reverse in the out years.* Also, as seen previously, the biofuel option does not take hold for several decades. Figure 5-3 shows that including non-CO_2 GHGs for payment increases the cumulative mitigation over time but does not alter the saturation and reversal pattern very much, because that pattern is driven entirely by the (CO_2) sequestration activity dynamics.

Selected Activity Scenarios

A project-based approach to mitigation is one in which specific GHG-mitigating activities are undertaken in distinct locations. One characteristic of project-based approaches is that their scope is generally limited—some activities are eligible

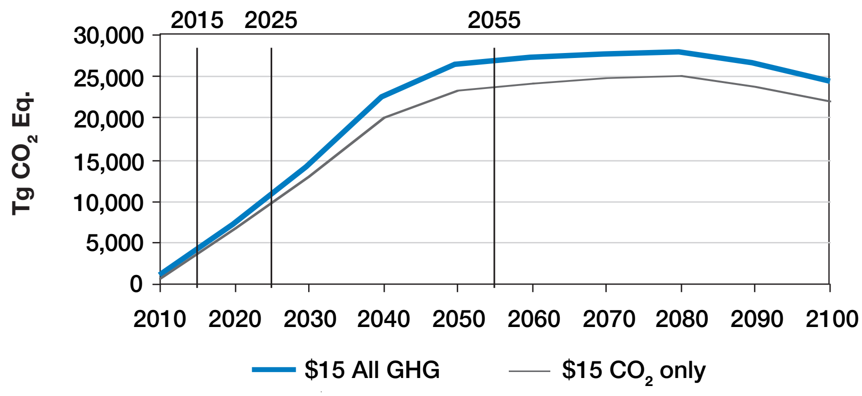
Table 5-6: National GHG Mitigation Totals in Key Years by Activity: Payment for CO_2 Only at \$15/t CO_2 Eq. (Includes Non-CO_2 GHGs)
Quantities are Tg CO_2 Eq. per year net emissions reduction below baseline.

	Year[a]		
Activity	**2015**	**2025**	**2055**
Afforestation	132	206	–180
Forest management	226	160	140
Agricultural soil carbon sequestration	201	209	–2
Fossil fuel mitigation from crop production	26	30	57
Agricultural CH_4 and N_2O mitigation	17	22	17
Biofuel offsets	0	0	56
All Activities	601	627	88

[a] Years represent midpoint of model decades 2010, 2020, and 2050, respectively.

Figure 5 3: Cumulative Mitigation: Payment for CO_2 Only (Includes Non CO_2 GHGs) vs. All GHGs at $15/t CO_2 Eq.

Quantities are Tg CO_2 Eq. cumulative net emissions reduction below baseline.



for GHG payments and others are not. Therefore, it is useful to evaluate the effects of a GHG incentive approach that targets its payments to a selected set of activities—to see the effect on the sectors' aggregate mitigation potential, and whether limiting eligible activities causes unintended consequences.

GHG mitigation projects can be seen as part of a broad set of landowner incentive programs administered by federal or state governments. There is a long history of these types of programs at the federal level over the last 50 years. Examples include the experiences of the Soil Bank Program, the Forestry Incentives Program (FIP), CRP, Wetlands Reserve Program (WRP), and various components of Farm Bill legislation including, of late, specific provisions to enhance carbon sequestration in forestry and agriculture.

To assess such mitigation activity at a smaller scale, five hypothetical scenarios are defined in Table 5-7. In each scenario, only one or a small number of activities receive GHG payments. All other activities within the forest and agriculture sectors face no price and thus receive no reward or penalty for changes in net GHG emissions.

The focus of these scenarios is on activities that (a) have large potential effects at low prices, as demonstrated in the results of Chapter 4 (e.g., agricultural soil carbon sequestration, forest management); (b) are easier to monitor because they involve a discrete land-use change (afforestation); or (c) are tied to other closely monitored market transactions (e.g., biofuels). Although three of the five scenarios pay for just a single activity, the other two separately evaluate payments for a somewhat wider range of forest and agricultural management activities.

Table 5-7: Selected Activity Scenarios

Activities Subject to Payments
Afforestation
Afforestation + forest management
Biofuels
Agricultural management (agricultural soil carbon + agricultural CH_4 and N_2O + crop management fossil fuels)
Agricultural soil carbon

Each scenario is evaluated at one of three price levels ($/t CO_2 Eq.) previously evaluated in Chapter 4:

- $15, constant over time;
- $3, rising at 1.5 percent per year; and
- $3, rising at 4 percent per year, capped at $30.

National Results

Results of the selected payment simulations are summarized in Table 5-8. This table shows the annual mitigation totals in key years (2015, 2025, 2055) for each of the specific activities under each of the price scenarios. The general patterns across the activities are similar to those found under these same price scenarios in Chapter 4 (where payments were comprehensively applied to all activities). Agricultural mitigation, specifically agricultural soil carbon sequestration, is the primary option at the lowest prices ($3, rising at 1.5 percent), forest carbon sequestration assumes a large role when prices are somewhat higher ($15, constant), and biofuels are a key strategy when GHG prices are expected to rise substantially in the future ($3, rising at 4 percent per year).

Regional Results

Each of the activities evaluated here has a unique geographic distribution of mitigation opportunities in response to the activity-specific GHG payments. The set of eligible activities, and landowner response to GHG price signals, for a given mitigation incentive is unlikely to be evenly distributed across regions. The regional implications and distribution are discussed for each activity below.

Payments for Afforestation Only

The $15/t CO_2 Eq. scenario is the only one of the three evaluated price scenarios showing much afforestation occurring at all. Under this scenario, afforestation is concentrated almost entirely in the South-Central United States (99 percent of total), with very small amounts in the Rocky Mountain and Pacific Northwest regions. Thus, under the type of targeted afforestation evaluated here, efforts could be concentrated regionally in the southern United States, which is where much of the nation's afforestation and reforestation are occurring at the present time. Under a more aggressive policy with higher prices, other regions would be drawn in as land is competed away from otherwise more profitable alternatives.

Payments for Afforestation + Forest Management Only

When forest management is combined with afforestation for targeted payments, this simulates the effect of full forest carbon incentives. As shown in Figure 5-4, this broadening of the incentives brings in contributions from other regions, for example, the Pacific Northwest, Westside, and Northeast. The predominant expansion, however, is into the Southeast United States, which

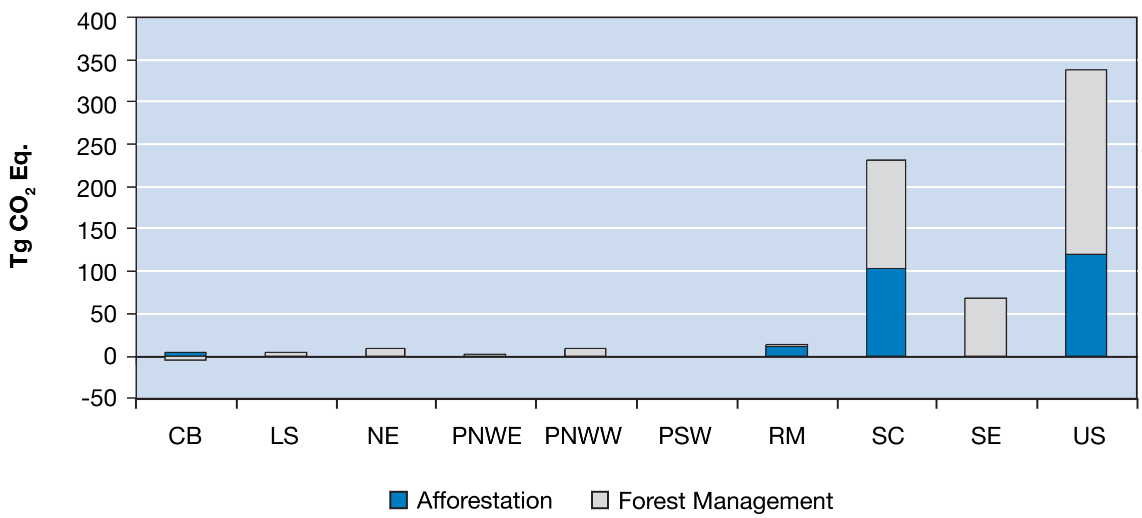
Table 5-8: GHG Mitigation under Payment for Specific Activity Scenarios
Quantities are Tg CO_2 Eq. per year net emissions reduction below baseline for key years: 2015, 2025, and 2055.

	GHG Price ($/t CO_2 Eq.)								
	$15			$3 @ 1.5%			$3 @ 4%		
Activity Paid for	**2015**	**2025**	**2055**	**2015**	**2025**	**2055**	**2015**	**2025**	**2055**
Afforestation	89	288	–173	0	0	–15[a]	0	0	38
Afforestation + forest management	350	366	–87	61	25	15	69	–58	162
Biofuels	0	0	237	0	0	0	0	0	352
Agricultural management	244	242	33	113	129	51	25	58	176
Agricultural soil carbon	191	184	–39	77	93	7	–5	16	143

Note: Scenarios are not additive because some overlap (e.g., afforestation and forest management).

[a] Carbon losses from afforestation in 2055 reflect harvesting of forests planted between 2025 and 2055 in this scenario.

Figure 5 4: GHG Mitigation under Payments for Afforestation and Forest Management Only at $15/t CO_2 Eq.: By Region
Quantities are Tg CO_2 Eq. per year net emissions reduction below baseline, annualized 2010 2110.



generates about 70 Tg CO_2 per year of additional carbon sequestration through forest management. The South-Central and Southeast regions together contribute about 90 percent of the total mitigation opportunities in the combined forest carbon scenario, thereby suggesting a fairly concentrated regional response to forest mitigation opportunities. This is not surprising given the southern states' large private timberland base and position as the nation's largest producer of timber and forest products.

Payment for Biofuels Only

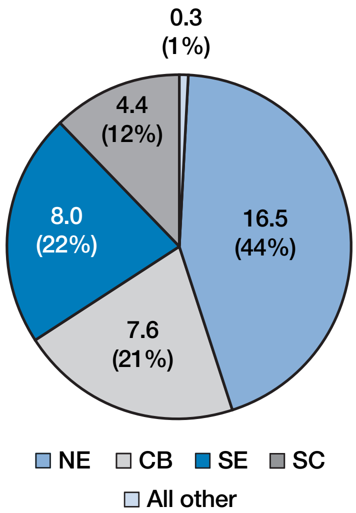
Consider two points raised in previous chapters about biofuel adoption: (1) adoption is only economic at prices of $15/t CO_2 Eq. and above and (2) biofuel demand is assumed to be capacity constrained in the short run, based on data from the EIA (Haq 2002). As a consequence, it is not surprising to find that $3 rising at 4 percent generates the largest targeted response from biofuel production of the three price scenarios evaluated. After about 40 years, the rising price exceeds $15, and biofuel use capacity is expected to grow throughout the century (see the biofuel demand assumptions referenced in Chapter 4). Together this implies that the capacity expands enough in time to take advantage of the higher prices. In contrast, the $15 per tonne constant price attracts some biofuel adoption over time, but the incentive does not get stronger as demand constraints relax. And the $3 per tonne price rising at 1.5 percent per year is insufficient to draw biofuel production even in the longer run.

The regional distribution of biofuel production/mitigation under this price scenario (Figure 5-5) is a bit wider than the regional distribution of forest mitigation opportunities, but the concentration is still entirely within the eastern United States.[3] The Northeast and Corn Belt regions together comprise about two-thirds of the biofuels opportunity, with almost all of the remainder in the South-Central and Southeast regions.

[3] Note that Figure 5-5 expresses mitigation quantities as cumulative totals over the entire projection period (2010–2110) rather than annualized totals. This is done because the discounting and annualization approach presented in Chapter 4 is not applicable under rising-price scenarios (see Herzog et al. 2003).

Figure 5 5: GHG Mitigation under Payments for Biofuel Offsets Only at $3/t CO_2 Eq., Rising at 4 Percent per Year, By Region

Quantities are cumulative mitigation (2010 2110) in petagrams (billion tonnes) CO_2 Eq.



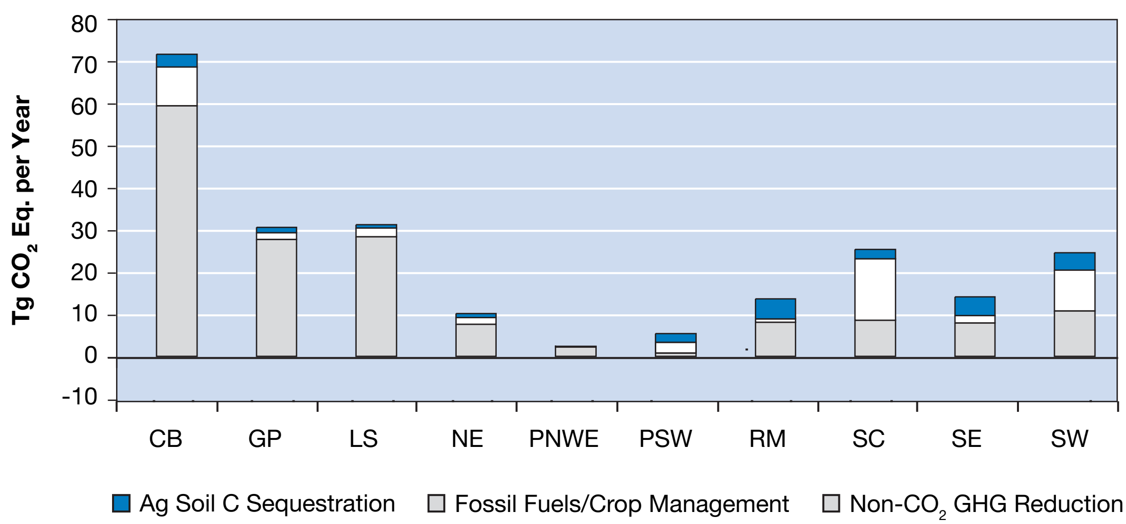
Payments for Agricultural Management Only

The agricultural management scenario targets payments for soil carbon sequestration, fossil fuel (CO_2) reductions for crop management practices, and non-CO_2 emission reductions through changes in crop and livestock management. In Figure 5-6, the regional distribution of these activities is depicted under the $15/t CO_2 Eq. constant-price scenario.

The scenario shows that the mitigation activities are widely distributed across the 10 main agricultural regions in the United States. Much of the mitigation is the result of agricultural soil carbon sequestration practices in the Corn Belt, Lake States, and Great Plains. There is also a modest amount of mitigation through reductions in fossil fuel emissions through crop practices in the South-central and Southwest United States. Non-CO_2 reductions are small, relative to the CO_2 options, but comprise a material share of the

Figure 5 6: GHG Mitigation by Region and Activity under Payments for Agricultural Management Only: $15/t CO_2 Eq.

Quantities are Tg CO_2 Eq. per year net emissions reduction below baseline, annualized 2010 2110.



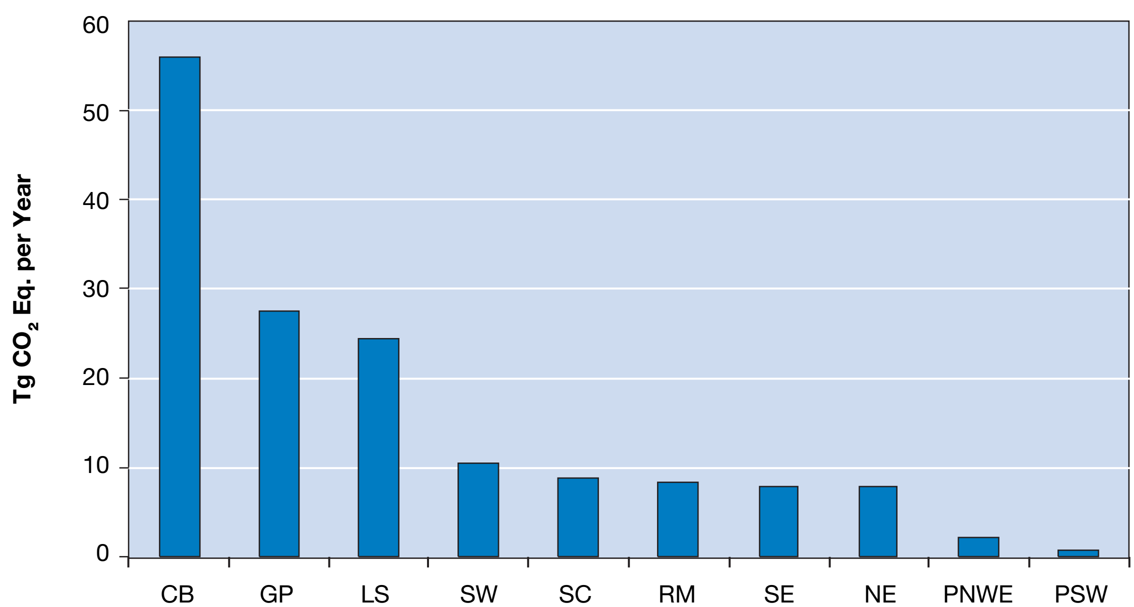
mitigation totals in the Southeast, Southwest, Rocky Mountains, and Corn Belt.

Payments for Agricultural Soil Carbon Sequestration Only

The regional distribution of mitigation under the agricultural soil carbon-only payment scenario for the \$15/t CO_2 Eq. constant-price scenario is illustrated in Figure 5-7. Landowner responses to the price incentives are distributed across all agricultural regions, with the Corn Belt generating the most annual soil carbon sequestration (56 Tg CO_2 Eq. per year), followed by the Great Plains (27 Tg) and Lake States (24 Tg). On the other end of the spectrum, there is virtually no soil carbon response (less than 3 Tg CO_2 Eq. per year) in the Pacific Northwest and Pacific Southwest because of biophysical and economic factors impeding adoption in those regions at the price trajectory evaluated. The remaining five regions generate a modest amount of sequestration in response to the incentive (between 8 and 11 Tg per year).

Figure 5 7: Regional Distribution of Soil Carbon Sequestration under Payment for Soil Carbon Only: \$15/t CO_2 Eq. Constant Price

Quantities are Tg CO_2 Eq. per year net emissions reduction below baseline, annualized 2010 2110.



CHAPTER 6

Implications of Mitigation via Selected Activities

Chapter 6 Summary

GHG mitigation activities may include project-based approaches (i.e., activity- and location-specific mitigation actions). Project-based GHG accounting can be used to ensure that the GHG mitigation attributed to a project reflects its net GHG reductions over time by including baseline GHG effects that would have occurred without project intervention, reversal of any carbon sequestered over time, and any leakage of GHG emissions outside project boundaries. Leakage effects are found to be more or less confined to the forest sector. The pay-for-afforestation-only scenario shows leakage of almost 25 percent, whereas leakage appears minimal if all forest carbon management activities receive payment. Leakage rates vary regionally and over time because of market responses and forest carbon dynamics. Most leakage due to targeted afforestation occurs within the first 2 decades. The broader the spatial scale in which market leakage is evaluated for an activity that produces commodities traded in that market, the higher the leakage estimated.

Leakage from individual activities in the agriculture sector appears to be small, roughly 0 to 5 percent in this analysis. Paying for additional sequestration through per-tonne CO_2 payments is more efficient than paying on a per-acre basis. Per-acre payments can be made more efficient (i.e., more closely match the efficiency of per-tonne CO_2 payments) through adjustments based on the land's carbon productivity potential.

As discussed in Chapter 5, it seems unlikely for a variety of reasons that fixed limits would be placed on GHG emissions from forestry and agriculture. Rather, selected opportunities for mitigation within these sectors may be seen as an effective means to offset GHG emissions elsewhere. As a result, the scope of eligible mitigation activities, GHGs, and land coverage within these sectors may be limited. For the purposes of this report, these activity- and location-specific GHG mitigation actions are called projects, referring to the actions the landowner takes on a specific tract of land to mitigate GHGs. For example, an individual farmer engaged in a tree-planting activity for the purposes of sequestering carbon would constitute a project. This chapter examines how limiting the scope and coverage of mitigation actions to project-based actions can affect the magnitude and distribution of GHG mitigation within the agricultural and forest sectors.

Observers have noted a number of important factors related to implementing these project-based approaches (CCBA 2004; IPCC 2000):

- demonstrating and quantifying net benefits,
- arranging and paying for the transactions, and
- ensuring sustainable development objectives are met.

The chapter continues with the discussion of several key technical issues related to quantifying GHG benefits, including *leakage, baseline-setting, and permanence or the potential reversibility of GHG* *benefits*. Other project-relevant factors include measurement, monitoring, and verification (MMV) of emission reductions or sequestration and assembly or aggregation of these quantified GHG benefits across market or program participants. MMV and assembly can impose transaction costs that should be considered when evaluating the economic attractiveness of mitigation projects. These issues are all discussed in more detail in the section that follows.

Because it is an aggregate model operating at regional resolution, FASOMGHG does not directly model implementation of activity at the individual project level. However, the model is flexible enough to limit the scope of incentives to subsets of activities, regions, and GHGs, thereby providing some insight into the effect of such limitations on mitigation potential. For instance, FASOMGHG is used in this chapter to estimate leakage potential when GHG incentives are confined to a subset of activities. In addition, the chapter includes an empirical analysis of modifying how incentives are provided to assess GHG payments on a per-acre, rather than per-tonne (t CO_2), basis (the approach thus far). Per-acre payments have been discussed as a means to economize on MMV and transaction costs (Antle et al. 2003).

The next section further discusses project-level implementation issues and the extent to which these factors can affect a project's net GHG benefits.

Project Quantification Issues and Costs

Project-based GHG mitigation activities are typically defined as those with clearly defined geographic boundaries, time frames, and institutional frameworks (IPCC 2000, Chapter 5). Certain characteristics of forestry and agricultural project activities can complicate the estimation of their net GHG mitigation benefits. Methods to address these concerns are discussed below.

Quantifying the Net GHG Contribution of Projects

One challenge with project-based approaches is ensuring that the amount of mitigation attributed to a particular project reflects the net contribution of that project to GHG reductions over time. Of particular importance is the notion that the GHG accounting captures

- the (baseline) GHG effects that would have occurred without the project intervention;
- the reversal or re-release of any carbon sequestered over time through harvesting, discontinuation of practices, or natural disturbance; and
- any leakage of GHG emissions that may have occurred outside the boundaries of the project.

Each of these issues is addressed below. Special emphasis is placed on the leakage issue because FASOMGHG model simulations in this report, in addition to other recent studies, are able to quantify leakage effects from activity-specific incentive programs.

Establishing Project Baselines

The net GHG benefit of mitigation at the project scale can be estimated as the additional GHG emission reductions (sequestration) that occur relative to emissions (sequestration) levels in the project's absence. This is the concept of additionality. To determine *additionality*, one can estimate what would happen under business-as-usual or BAU without the project, which is referred to as the project *baseline* (IPCC [2000], Chapter 5).

A number of analyses and existing GHG mitigation programs have focused on the primacy and complexity of setting a baseline case to estimate GHG mitigation benefits (e.g., IPCC [2000], Chapter 5). Demonstrating additionality requires establishing a project baseline. In the case of GHG emission reduction projects in sectors such as electricity generation, a baseline might reflect the GHG emission rate that would prevail if the electricity were generated using standard technologies and fuels for a given sector and region. In forest- or agricultural-sector projects, however, it is a bit more complicated. First, an estimation of the land-use practices that would occur under BAU may be required. This may require using historical data on land use and management practices to provide an empirical foundation for BAU. The emergence of remotely sensed land-use data in a digitized format expands the possibilities for more complex and rigorous analysis of baseline land-use behavior. Then, once the land-use or management practice baseline is determined, estimation of what the emissions or sequestration rate would be under each of the BAU land-use practices can complete the baseline quantification.

No generally agreed methodology yet exists in the United States or internationally for project baseline setting by activity and region, although numerous efforts are under way to develop consistent protocols (CCBA 2004). It is beyond the scope of this report to assess project-level baseline options. Those methods are still largely in the proposal and evaluation stages. However, the development of project baselines is a cost of project development that is not directly captured in the economic analysis herein. This and other potential project transaction costs are addressed further below.

The focus of the discussion in this section has been on baselines at the *project level*, but sector-level baselines also are used in the broader analyses presented in Chapters 4 and 5. All mitigation results in the report are presented relative to the FASOMGHG sector baselines for forestry and agriculture. Thus, they are consistent with the concept of additionality discussed here. However, the model scenarios in those chapters do *not* impose additionality as a requirement for GHG payment—in essence all GHG effects are potentially eligible for payment.

Duration and Potential Reversal of GHG Benefits (Permanence)

As discussed throughout this report, GHG mitigation in the forest and agriculture sectors is susceptible to reversal. This is particularly relevant when carbon is sequestered for some time and then re-released accidentally (e.g., through wildfire) or as part of a planned intervention such as harvesting or land-use change. A complete accounting framework would capture both GHG releases to and GHG removals (sequestration) from the atmosphere. The FASOMGHG model scenarios presented in this report do capture such carbon losses from intentional releases tied to the harvesting and land-use decisions embedded in the model. Accidental carbon releases through fire, insects, and diseases are captured in the model via the biophysical yield functions used for forestry and agriculture, which are generally based on average yields, and therefore implicitly capture the persistent accidental losses from ambient sources.

However, a number of logistical factors may make such a complete accounting of GHG releases and removals over time as modeled in FASOMGHG for this report difficult for individual forestry and agriculture projects. These factors revolve around two key questions: (1) how does a set of mitigation activities or individual projects address the risk of reversal of GHG benefits during the lifetime of the program, and (2) how does it address this risk of reversal once the program or project has ended? Specific factors to consider include the following:

- Natural disturbance and other *force majeure* effects occur with uncertainty.
- Catastrophic loss of carbon could cause catastrophic financial losses for an investor.
- Project contracts generally have finite lives.

The first two factors relate to the difficulty of dealing with the risks of release when the project is under way. The unpredictability of project risk complicates project planning and decisions on actions that might be taken to reduce risks. By and large, the prospect that the investor might suffer catastrophic loss of the asset—carbon benefits, plus the normal accompanying economic asset, such as timber—makes the investment more risky and therefore reduces its attractiveness. If the risks are large enough, investors may seek ways to cover these potential losses if they proceed with the investment. Specific instruments for covering these risks (insurance policies, pooling projects with similar or dissimilar characteristics, holding some achieved mitigation benefits in reserve) might be considered, although the markets for these financial instruments may be a bit thin at this time (Subak 2003).

The other critical issue is that the project will typically involve a contract that expires after some period of time. The question then arises: how do you account for risks of release after a project ends? Various parties have proposed contractual options to address the risk of reversal in (primarily) carbon sequestration projects. These options are described in Table 6-1.

The options in Table 6-1 address how to account for reversal when it occurs. But project developers may also want to consider the actions they can take to minimize the risk of GHG reversal at the project design stage. One approach is to develop a carbon reversibility management plan, which lays out steps for identifying reversal risks, evaluating options for minimizing these risks, developing liability or compensation for risk when it occurs, and monitoring risks over the life of the project (WRI-WBCSD 2003).

Analytic consideration of project reversibility is outside the scope of this analysis and remains a topic of continued dialog and research.

Assessing the Potential for Leakage

Project-based mitigation approaches run the risk that some of the direct GHG benefits of these efforts will be undercut by leakage of emissions outside the boundaries of the project. IPCC (2000) defines leakage as "the unanticipated decrease or increase in GHG benefits outside of the project's accounting boundary (the boundary defined for the purpose of estimating the project's net GHG impact) as a result of project activities." The notion that project-based mitigation can generate leakage is a widely accepted concept.

Table 6-1: Candidate Approaches for Accounting for Reversal Risk from Carbon-Based GHG Mitigation Projects

Approach	Description	Sources
Comprehensive accounting		
Pay-as-you-go *Used in this report with FASOMGHG model*	Accounts for both carbon storage and carbon release to the atmosphere. This approach is consistent with national GHG inventory accounting practices. Addresses reversal as long as activity is reported in continuous program, including reversal beyond the finite life of a project.	IPCC (1996, 2000); Feng et al. (2001)
Approaches to project reversal risk (if comprehensive accounting not used)		
Temporary crediting	Designed to account explicitly for the fact that sequestration projects may only yield temporary reductions in atmospheric CO_2 concentrations. Three general approaches: • expiring, or temporary, Certified Emission Reductions, or tCER; • carbon "rental"; and • carbon "leasing."	Colombian Ministry of the Environment (2000); Blanco and Forner (2000); Chomitz (2000); Marland et al. (2001) ; Moura Costa (1996); Dutschke (2001); Dutschke (2002)
Ex ante discounting	Directly estimate and account for predicted reversal through management, harvesting, etc., in determining sequestration tonnes assigned at the beginning of the project.	McCarl and Murray (2002); Lewandrowski et al. (2004)

The challenge is quantifying leakage attributable to a specific activity and location. Leakage is relevant for assessing the effectiveness of programs that target a subset of land-based activities such as afforestation, biofuels, or agricultural soil carbon sequestration, as in the case of the scenarios presented in Chapter 5. Therefore, it is important to recognize the potential for leakage and to develop methods to

- target or design projects or sets of mitigation activities to minimize leakage,
- monitor leakage after projects or sets of mitigation activities are implemented,
- quantify the magnitude of leakage when it exists, and
- take leakage into consideration when estimating net GHG benefits of activities.

There has been little quantification of leakage effects in the forest and agriculture sectors. Chomitz (2002) uses an analytical model to compare the potential for leakage from forestry projects to that from energy-sector projects. Chomitz shows that forestry projects are not systematically more prone to leakage than energy-sector ones, as some parties have argued.

The five selected activity scenarios presented in Chapter 5 provide a framework by which to estimate the extent of leakage from selected, noncomprehensive activity sets. In each case, only one activity or subset of activities receives GHG payments. The GHG mitigation from each activity is then quantified and presented as the direct benefits of a selected activity. Although payments may only be applied to a single activity or subset, the FASOMGHG model tracks GHG effects throughout the entire U.S. forest and agriculture sectors. Therefore, one can compare the direct GHG benefits of each set of targeted payments with the net GHG effects for the entire combined sectors to quantify if and to what extent the direct benefits are offset by leakage somewhere else in the system. Leakage is calculated as a percentage of the direct benefits, accordingly:

$$\text{Leakage percent} = \frac{\text{Indirect GHG emissions from nontargeted activity}}{\text{Direct GHG reductions from targeted activity}} \times 100.$$

As has been demonstrated throughout this report, GHG mitigation actions in forestry and agriculture generate variable levels of mitigation over time, particularly for the sequestration options. To capture these fluctuating GHG effects in a single measure of leakage for each activity, the GHG quantity terms in the numerator and denominator of the leakage equation are expressed in annualized equivalent values for the corresponding projection period, decades 2010 to 2110. The implications of choosing a shorter time horizon for leakage estimation are discussed further below.

Table 6-2 presents the corresponding leakage estimates for each of the selected activity scenarios, evaluated at a single GHG price of \$15/t CO_2 Eq.[1] for each of the FASOMGHG-selected activity scenarios from Chapter 5. The most significant finding is that only one of the activities, afforestation, generates appreciable amounts of leakage (24 percent).

Once afforestation and forest management are combined and targeted together, almost all of the leakage vanishes because essentially all of the leakage from mitigation incentives that induce afforestation occurs through carbon reductions from reduced forest management. This reduced forest management is caused by the corresponding decline in timber prices and incentive to invest in forest management caused by increasing the area of land in forests. When forest management is eligible to receive incentive payments, this leakage largely goes away. In fact, the leakage effect is even slightly *negative*, meaning that there is a small amount of "good" leakage (reduced net emissions) spilling out of the forest sector into the agriculture

[1] Leakage effects in Table 6-2 are presented for the \$15/tonne CO_2 Eq. price because that price induces some activity in all categories. The lower prices evaluated in Chapter 5 (\$3/tonne, rising at 1.5 percent and 4 percent per year) generate too little afforestation to discuss leakage effects for that activity.

sector, further augmenting the benefits of the direct payments for forest carbon. This good leakage occurs as the sectors reallocate land and management in response to the forest-sector incentives, and the reallocation of resources in agriculture leads to a slight decline in agricultural emissions (i.e., an increase in indirect mitigation). These leakage values are small in both absolute and percentage terms. Given the uncertainty involved in any complex modeling exercise as this, the more important message is that leakage appears minimal if all forest carbon activities are targeted for payment together. Likewise, the results in Table 6-2 suggest that leakage from payments targeting biofuels and agricultural activities is quite small, as well, roughly 0 to 6 percent.

The time horizon for GHG mitigation, particularly forest carbon sequestration, is long, with actions taken in one year having implications for many decades down the road. However, the time horizon for projects or sets of reported mitigation activities is likely to be shorter, confined by the institutional realities of changing policy priorities and of investment time frames. The discussion in Box 6-1 considers the implications of viewing leakage effects for an afforestation project from a shorter time frame than the 100-year projection period used to generate the leakage estimates in Table 6-2. It concludes that for the afforestation $15/t CO_2 scenario reviewed, the leakage rate is unchanged from the 100-year value under a 50-year time frame of analysis. But it significantly increases under a 20-year time frame because most afforestation leakage occurs in the first few decades.

Leakage from Forest Carbon Sequestration: A Closer Examination

Because the results in Table 6-2 suggest leakage effects are more or less confined to the forest sector, we take a closer look at forest carbon leakage, further detailing the FASOMGHG results and drawing from other published forest carbon leakage estimates.

Focusing first on the leakage results from paying for afforestation only, the 137 Tg CO_2 per year of direct GHG benefits from afforestation is offset by leakage of about 33 Tg CO_2, or about 24 percent. Thus, the net GHG benefit is 104 Tg CO_2, when leakage is taken into account.

Table 6-2: Leakage Estimates by Mitigation Activity at a GHG Price of $15/t CO_2 Eq.
All quantities are on an annualized basis for the time period 2010–2110.

Selected Mitigation Activities	A GHG Effects of Targeted Payment (Tg CO_2 Eq.)	B Net GHG Effects of All Activities (Tg CO_2 Eq.)	C Indirect GHG Effects from Nontargeted Activity[a] (Tg CO_2 Eq.)	D Leakage Rate[b] (%)
Afforestation only	137	104	–33	24.0
Afforestation + forest management	338	348	10	–2.8
Biofuels	84	83	–1	0.2
Agricultural management	230	231	1	–0.1
Agricultural soil carbon	154	145	–9	5.7

[a] Indirect effects: C = (B – A).

[b] Leakage rate: D = –(C/A) x 100; rounding occurs in table.

Note: Negative leakage rate in D refers to beneficial leakage (i.e., additional mitigation outside the selected activity region, also called positive leakage).

In what activities and regions can the leakage be found? Figure 6-1 provides some insights. As described in Chapter 5, virtually all of the afforestation response in the afforestation-only payment scenario occurs in the South-Central states (about 99 percent). This is depicted in the left side of Figure 6-1. The right side of Figure 6-1 shows the regional and activity nature of the leakage induced by the afforestation payments. The primary source of leakage is, as expected, from the decline in carbon from forest management. But Figure 6-1 shows two other nonforest leakage effects caused by the movement of land from agriculture to forests within the South-Central region. First, this land movement produces a decline in crop-related fossil fuel (CO_2) emissions within the region, which is

Box 6-1: Shortening the Time Horizon for Quantifying Leakage

The leakage estimates in Table 6-2 are calculated using the annualized values for the time stream of GHG mitigation effects over the entire FASOMGHG projection period, spanning the time period 2010 to 2110. These annualized values capture in one summary metric the entire projected mitigation profile over a long period of time. However, analysts also might be interested in confining measurement of leakage just to a set period of time pertinent to a given mitigation reporting framework (e.g., 2010) or the time frame of a given project. This may be particularly applicable to highly time-dynamic mitigation options such as afforestation. Therefore, we recalculate the leakage estimates for the afforestation scenario, confining the time period of observation to 5 decades and 2 decades, respectively, and ignoring all future GHG effects beyond that. The effect of the change in time horizon is reflected below for the $15/tonne CO_2 Eq. GHG price.

Targeted Mitigation Activity: Afforestation at $15/t CO_2 Eq.
All GHG quantities in the table are annualized over the time horizon indicated in far left column.

Leakage Time Horizon	A GHG Effects of Targeted Payment (Tg CO_2 Eq.)	B Net GHG Effects of All Activities (Tg CO_2 Eq.)	C Indirect GHG Effects from Nontargeted Activity[a] (Tg CO_2 Eq.)	D Leakage Rate[b] (%)
10 decades	137.4	104.4	–33.0	24.0%
5 decades	170.7	129.7	–41.0	24.0%
2 decades	208.5	127.7	–80.8	38.8%

[a] Indirect effects: C = (B – A).

[b] Leakage rate: D = –(C/A) x 100; rounding occurs in table.

Note: Negative indirect effects produce positive leakage rate.

Shortening the time horizon from 10 to 5 decades, while it affects the absolute annualized GHG mitigation quantities, does not affect the relative leakage rate. In essence, most of the important feedbacks between afforestation, forest management, and other activities are resolved in the first 5 decades.

However, when the time horizon is shortened to just 2 decades, both the absolute annualized mitigation values and the leakage rate are substantially affected. The leakage rate goes up because the initial response to an afforestation incentive payment is a decline in the area and intensity of managed forests not subject to the afforestation payments. This decline leads to a large drop in carbon on these other managed forests in the initial decades, which eventually evens out.

However, when the time horizon is confined to 2 decades, these initial declines in forest management carbon have a larger effect relative to the direct afforestation GHG benefits, which will continue to accumulate for several more years after the second decade.

This exercise suggests that most of the leakage effect from an afforestation project occurs in the first couple of decades. Therefore, if any project-level accounting standard chooses to ignore all carbon effects beyond the second decade, leakage effects will appear to be higher than their projected effect over a longer time-frame.

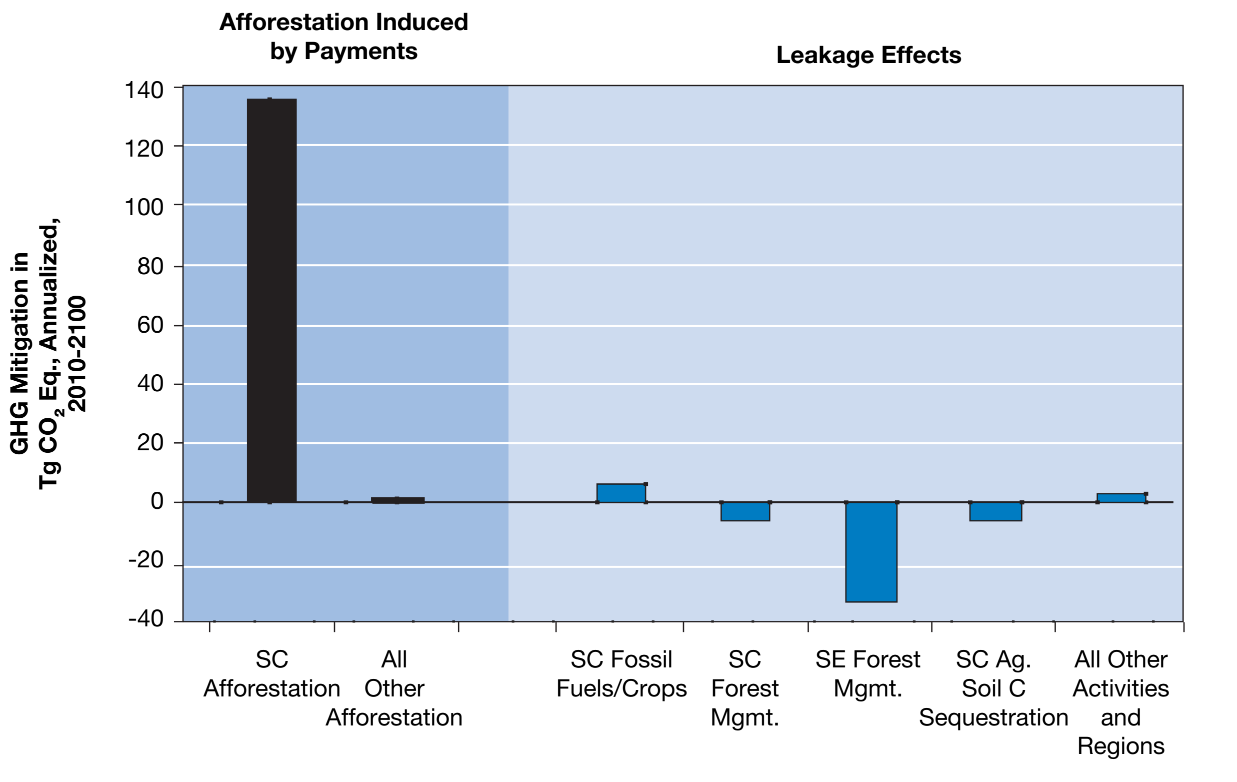
shown in Figure 6-1 as positive mitigation (i.e., "good" leakage). Second, this land movement reduces the South-Central cropland base and leads to more intensive cultivation practices, which increase soil carbon loss in the region (i.e., "bad" leakage).

The phenomena depicted in Figure 6-1 imply that this afforestation scenario, which turns out to be regionally confined to the South-Central United States for the scenario evaluated, has leakage effects that are also regionally confined. Virtually all of the leakage occurs within the two southern (South-Central and Southeast) regions. Most of the market feedback from this level of afforestation would have spatial limitations, because land-use change has localized tendencies. Forest management responses are confined to the South-Central and Southeast regions, because that is where most of the country's intensively managed forests are located.

Leakage Estimates from the Literature

A study by Murray, McCarl, and Lee (2004) uses FASOMGHG's precursor, the FASOM model, to estimate leakage from different U.S. forest carbon sequestration activities. Other than using the same basic modeling foundation, the Murray et al. study differs from this report in a number of ways. For example, the Murray et al. study includes scenarios for forest preservation and avoided deforestation in addition to afforestation but does not estimate leakage from agriculture or biofuel production.[2] That study also tries to simulate

Figure 6 1: Regional Leakage Flows for Afforestation Only Payment Scenario: \$15/t CO_2 Eq.



Note: Negative sign (e.g., South-Central Forest Mgmt.) is leakage, and positive sign is beneficial leakage (i.e., additional mitigation outside targeted activity region).

[2] Forest preservation refers to the withdrawal of existing forest from the timber harvesting base, also referred to sometimes as a forest set-aside. Avoided deforestation refers to keeping land in forest that would otherwise be converted to another use. Once deforestation is avoided, the forest can either be preserved (no timber harvesting allowed) or maintained as a timber-producing forest with harvests allowed.

smaller, region-specific mitigation incentives, in contrast to the national-level payment scenarios evaluated here. Their leakage estimates are derived by simulating a specific level of mitigation in a given region for a single activity and then comparing model results for that selected activity level to the United States as a whole. They assess forest set-asides or preservation of lands likely to remain in forest (100,000 acres of old growth in the PNW and 600,000 acres in the South), avoided deforestation on lands with potential for conversion to agriculture, and afforestation (a 10-million-acre level in each region). These two studies taken together can provide some sense of the range of forest carbon leakage estimates in the United States by activity and region.

The national afforestation estimate in Table 6-2 (24 percent) falls in the 18 to 43 percent range found for regional leakage in U.S. afforestation by Murray et al. (see Table 6-3). But in contrast to this study, where afforestation generates the largest leakage of any of the activity scenarios evaluated, Murray et al. find in some cases larger leakage estimates for the other forest-sector activities: forest preservation and avoided deforestation (Table 6-4).

Table 6-3: Afforestation Regional Leakage Estimates from Murray et al. (2004)

Region	Leakage %
Northeast	23.3
Lake States	18.3
Corn Belt	30.2
Southeast	40.6
South-Central	42.5

Forest preservation leakage was found to vary from 16 percent in one region (PNWW) to almost 70 percent in another (South-Central). Forest preservation can generate relatively high leakage if it simply shifts harvests to another location, which is what the results for the South-Central region suggest. There is less leakage from preservation in the PNWW, in part, because the harvests are shifted to other regions where the losses in carbon would not be as high as they are in the carbon-rich forests of the Pacific Northwest.

Leakage for avoided deforestation is found to vary from slightly positive leakage (i.e., net positive GHG effects off-site) in the Corn Belt, to about 8

Table 6-4: Forest Preservation and Avoided Deforestation Regional Leakage Results from Murray et al. (2004)

Region	Leakage %	
Forest Preservation (Set-aside)		
Pacific Northwest-Westside (PNWW)	16.2	
South-Central (SC)	68.8	
	Leakage % Harvesting Allowed on Preserved Forests?	
Region	**No**	**Yes**
Avoided Deforestation		
Pacific NW-East Side (PNWE)	8.9	7.9
Northeast (NE)	43.1	41.4
Lake States (LS)	92.2	73.4
Corn Belt (CB)	31.5	–4.4
South-Central (SC)	28.8	21.3

percent for the PNWE, to leakage topping 40 percent in the Northeast and Lake States, where it reaches 73 to 92 percent. Leakage is higher when no harvesting is allowed on the lands saved from deforestation, as harvests are shifted to other forests as described above.

Other studies in the literature do not address GHG leakage directly but focus on the market activity-shifting that underlies GHG leakage. For instance, Wear and Murray (2004) used an econometric model of the U.S. softwood lumber market to simulate the effect of reducing timber sales in the Pacific Northwest. Federal restrictions on the harvest of old-growth timber in the 1990s resulted in an 85 percent reduction in harvest volume on public lands. Wear and Murray found that 43 percent of timber harvest reductions in the West region alone leaked away into other harvests within the region, that 58 percent leakage occurred when the continental United States was considered, and that fully 84 percent of the leakage occurred when the United States and Canada were included in the analysis.

In the area of agricultural soil management, previous work by Wu (2000) and Wu, Zilberman, and Babcock (2001) examines program “slippage” from CRP adoption in the United States. Slippage refers to the phenomena by which land retirement into the CRP can induce lands outside the program to enter into cultivation and offset the direct benefits of land retirement. These studies find that 10 to 20 percent of direct CRP benefits are offset by slippage. The agricultural soil carbon sequestration leakage estimate in this study (5.7 percent) is slightly below, but in the same ballpark as, those slippage estimates.

Leakage Summary

Several key findings emerge on leakage from both this study and the extant literature.

First, *afforestation, forest preservation, and avoided deforestation, if targeted individually, could have significant to very large leakage*—depending on the region and how incentives for mitigation are provided. The forest economy involves multiple feedbacks between markets for land, other inputs, and timber. So when GHG incentives are confined to just one part of the forest production system—land use, management, harvest timing—it is more than likely that another part of the system will be affected, often in ways that diminish the net GHG mitigation for the entire forest system. For instance, when afforestation is awarded GHG price incentives and forest management is not, then forest management intensity and carbon tend to decline. Likewise, when harvests are restricted in certain areas but allowed to vary freely elsewhere, the market will tend to shift the harvests and cause leakage.

Second, this key finding follows directly from the first, namely, *leakage appears minimal if all forest carbon activities are included for payment together.* For instance, if afforestation and forest management are targeted together, very little leakage occurs because leakage from afforestation occurs through carbon reductions from reduced forest management. Forest management is reduced because of the corresponding decline in timber prices and incentive to invest in forest management. When incentives are provided to forest management, “good” leakage may occur as the sectors reallocate land and management in response to the forest-sector incentives, and the reallocation of resources in agriculture leads to a slight decline in agricultural emissions.

Third, *leakage from individual activities outside the forest sector appears to be small*. The results in this study suggest that leakage from payments targeting biofuels and agricultural activities is quite small, roughly 0 to 5 percent. Therefore, any accounting adjustments for leakage could fall more heavily on forest-sector activities than on agriculture.

Fourth, *leakage varies by region for a given mitigation activity, reflecting differing levels of market response for wood products or other commodities within and across regions.*

Fifth, *leakage rates vary over time because of forest carbon dynamics; therefore, leakage estimates may* *vary depending on the time frame of analysis.* FASOMGHG results here show that most leakage due to targeted afforestation occurs within the first 2 decades.

Finally, while only early analyses are available to date, it appears that *the broader the spatial scale in which market leakage is evaluated for an activity that produces commodities traded in that market, the higher the leakage estimated*. The FASOMGHG model does not capture leakage due to GHG incentive responses outside the United States. However, the FASOMGHG results in this study show that, at least for afforestation, leakage may be relatively confined to within the regions directly affected by incentives for mitigation. For harvest restrictions, the spatial scale is wider, because the results of Wear and Murray (2004) clearly show higher leakage rates as the number of regions in the North American timber market included in the analysis increased. Therefore, a more global view is needed to better assess mitigation activities and incentive approaches that might cause shifts in production to other regions of the world.

Other Project Implementation Considerations

A number of other implementation issues should be considered when evaluating project-based or other selected activity approaches to GHG mitigation in the forest and agriculture sectors. These implementation issues are reviewed below and are not explicitly reflected in the FASOMGHG scenarios throughout this report.

Measurement, Monitoring, and Verification (MMV)

MMV is the process by which the amount of GHG mitigated by a project is measured, the measurements are monitored over time to ensure that all relevant GHG flows are accounted for, and the monitored measurements are verified to demonstrate to external parties that the emission reductions and/or sequestration have occurred. For carbon sequestration projects, this process can involve a range of methods, including repeated measurement of sample plots using refined scientific procedures, collection and analysis of aerial photographic and satellite image data, and use of ecosystem process models to simulate likely outcomes when observation is difficult.

The ability to measure GHG effects in forestry and agriculture depends a great deal on the

- GHG of interest,
- number and location of affected carbon storage pools,
- way in which the GHGs are exchanged between ecosystems and the atmosphere,
- precision that is acceptable for reporting and verification purposes, and
- cost one is willing to pay to develop the measurements.

For instance, the amount of carbon stored above ground in trees is relatively easy to measure, but the amount of carbon stored in soils is more difficult. Detecting the change in soil carbon can generally be more difficult because of a high degree of spatial variability and the fact that any change may be small relative to the size of the existing soil carbon stock. See the following for more detail on MMV issues for forestry and agricultural sequestration projects: Chapter 5 (e.g., Table 5-7) in IPCC (2000); CASMGS (2003) Carbon Measurement and Monitoring Forum at www.oznet.ksu.edu/ctec/ Fall_Forum.htm; and Brown (2002).

CH_4 emissions from livestock enteric fermentation are difficult to measure at the herd level, but monitoring CH_4 emissions avoided through manure management systems that use the CH_4 for energy production is relatively easy, because the CH_4 is directly tied to the amount of kWh produced. Likewise, CO_2 emissions reduction from replacing fossil fuels with biofuels is a relatively straightforward measurement because of its correspondence to actual, observable market transactions. In light of these factors, MMV requirements need to be taken into consideration before embarking on a project, because this can affect the ability to demonstrate credible mitigation effects and can substantially affect the cost of the project.

Market Assembly and Brokering of Mitigation Activities

For a GHG mitigation market to work, buyers and sellers must be brought together to consummate transactions. Some process is necessary by which GHG mitigation benefits are assembled and brokered. Without this, the economic incentives for mitigation may not flow to those who can supply the mitigation at a cost that is less than or equal to the price that a buyer is willing to pay. When there are few numbers of buyers and sellers (i.e., the market is thin), this may create an inefficient process of search and discovery. When there are more market participants, a role for third parties to broker and assemble transactions could evolve. Consequently, the development of this market-making infrastructure may need to be considered in any market-based GHG mitigation program.

Even in the case of government-sponsored landowner incentive programs, rather than a private market for mitigation, some infrastructure is necessary for delivering the incentive to the landowner. In the United States, there is a long history of these programs being delivered to farmers, ranchers, and forestland owners through a variety of outreach mechanisms such as agricultural and forestry extension programs at federal and state agencies and universities.

Transaction Costs

The various implementation issues just discussed (e.g., contracting, risk management procedures, MMV, market assembly) all impose what can be termed collectively as transaction costs on developing and operating a GHG mitigation project. The liability for these transaction costs may fall on the buyer, the seller, or both parties.

If the seller is liable, this adds to their costs and increases the amount they need to be compensated to voluntarily engage in the transaction. If the buyer is liable, this lowers the amount they are willing to pay for a unit of mitigation, because the full cost of the unit includes the transaction cost. But regardless of who bears the direct liability, the cost and risk of undertaking these activities directly affect the value of the transaction itself.

Many of these transaction costs operate under scale economies; that is, because they involve many costs that are largely fixed, the cost per transaction declines with the number of transactions covered (Mooney et al. 2004b). For example, a reversal risk management plan and MMV plan will not likely be 10 times larger for a project generating 100,000 t CO_2 Eq. per year of mitigation than one that generates 10,000 t CO_2 Eq. per year. In addition, GHG contracts may need to be bundled or aggregated to a minimum lot size for market exchange. For instance, the Chicago Climate Exchange, a voluntary system for GHG trading, requires a minimum trading block of 12,500 t CO_2 Eq. If conservation tillage practices generate 0.5 t CO_2 Eq., per acre per year, this will require bundling across 25,000 acres. Therefore, large operations will be able to bundle more cost-effectively than small ones. Finally, market assembly or brokering costs are likely to be much lower on a per-unit basis for a large volume market than for a small volume market. Note that the absolute size of the transaction costs per unit does not matter as much as the ratio of that cost to the per-unit value of the transaction.

Evidence on the size of transaction costs associated with forest and agricultural practices is quite limited. Relatively few GHG mitigation projects in forestry and very few in agriculture have been implemented in the field. Certain components, such as the cost of MMV, have been recorded in some cases and have been relatively low for projects operating on a fairly large scale. Kadyszewski (2001) estimates costs of less than $0.25/t C Eq. ($0.07/t CO_2 Eq.) for forest carbon measurement. Mooney et al. (2004a) estimate the measurement and monitoring costs of soil carbon benefits from the adoption of more intensive cropping practices in Montana as generally less than $1/t C Eq. ($0.30 per t CO_2 Eq.). However, costs will depend primarily on the degree of precision required, heterogeneity of the landscape, frequency of sampling, and project size (Mooney et al. 2004a; Brown, Masera, and Sathaye 2000).

While measurement costs may be low, on the other hand anecdotal evidence suggests that some transaction cost components could be considerable. For instance, if trading tends to be conducted in large units (e.g., 100,000 t CO_2 blocks), given the sequestration rates per unit of output for many of the activities in forestry and agriculture, each transaction could require aggregating hundreds or thousands of landowners. These costs are likely to be considerable. Alston and Hurd (1990) found that the costs of delivering government programs to farmers in the United States are on the order of 25 to 50 percent of the value of the program payments.

The FASOMGHG model simulations throughout this report do not include transaction costs. This is not problematic if transaction costs are low, because their omission from the analysis would then be trivial. If transaction costs are uniform across options, then one can adjust the GHG price incentives accordingly and roughly determine the mitigation potential. On the other hand, if per-unit transaction costs differ among afforestation, forest management, agricultural soil carbon sequestration, and biofuels, then the portfolio of options selected at each GHG price will change. Consistent data on the size and distribution of transaction costs across mitigation options would be a helpful addition to analyses such as those presented in this report.

Preliminary Assessment of Implementation Factors by Major Mitigation Activity

The discussion above suggests that major mitigation activities have different characteristics with regard to project-based implementation. Tables 6-5 and 6-6 evaluate mitigation options across the various implementation issues, quantitatively where FASOMGHG results are available, and qualitatively otherwise. A rigorous comparison of activities along each of the implementation factors requires additional analysis and is beyond the scope of this study. A review of Tables 6-5 and 6-6 suggests the following:

- Afforestation has significant leakage varying by regional market conditions, but MMV and establishment of a baseline may be relatively straightforward because land-use change can be observed. Additionality is likely to be high. Reversal risk is relatively high without constraints imposed.
- Forest management, which is an economic option at a wide range of options, has some project implementation challenges. MMV and baseline setting may be more challenging than afforestation, for example, because changes in management practices rather than readily observable changes in land use are involved. Setting a baseline and determining additionality may be more difficult.
- Agricultural soil carbon sequestration appears to have low leakage but may require significant site-specific data to determine a baseline and additionality and monitor project activities. Risk of reversal from increased tillage is moderate to high and may require site-specific data to assess.
- Agricultural CH_4 and N_2O mitigation options and biofuels appear to have low leakage and may have a low likelihood of reversal. Some options (e.g., CH_4 capture from manure management and biofuels) in general appear to be readily monitorable and likely to be additional, while others (e.g., soil N_2O mitigation options) may be more challenging to evaluate for these issues.
- Biofuel offsets, though a relatively high-cost option in the economic analyses above, have a number of implementation advantages in that they are relatively easy to measure, monitor, and verify; highly additional under current energy market conditions; and have low reversal risk.

Taken together, it is interesting to observe that some of the lower cost mitigation options found in the economic analyses (e.g., forest management and agricultural soil carbon sequestration) may have implementation challenges, in contrast to options such as biofuels implementation and afforestation, which have higher opportunity costs (in the economic analysis) but possibly lower implementation transaction costs.

Table 6-5: Implementation Issues for Selected Activities and Projects: Leakage Estimates from FASOMGHG and MMV

Activity	Leakage Potential (and Estimates)	MMV Difficulty
Afforestation	Moderate U.S. average: 28% Regions: 18-42%[a]	Relatively easy to measure, monitor, and verify forest establishment. Measuring carbon is relatively straightforward for above-ground carbon, less so for below-ground carbon. Models can be used instead of direct measurement if program allows.
Forest management	Likely some leakage through reduced afforestation No separate estimates available	Moderate to difficult to measure, monitor, and verify specific management actions attributable to a project. Measuring carbon in established stands is not exceedingly difficult, but tying the change in carbon to specific practices may be.
Agricultural soil carbon sequestration	Low 6%	Easy-moderate to measure, monitor, and verify across adopting practices. Moderate–difficult to directly estimate carbon consequences across the landscape. Models can be used instead of direct measurement if program allows.
Agricultural CH_4 and N_2O mitigation	Low NA	Easy (e.g., for manure management CH_4 tied to electricity-generating systems), difficult for dispersed emissions (e.g., enteric fermentation at the herd level).
Biofuel offsets	Low <1%	Easily tied to the biofuel market transactions.

[a] Results from five regions in Murray et al. (2004) reported above.

Per-Acre Payments for Carbon Sequestration to Address Measurement Difficulties

GHG mitigation activity could be designed to economize on transaction costs, particularly MMV costs. The incentive approaches evaluated thus far have paid for GHG mitigation on a dollar-per-tonne basis. An alternative is for payments to be based on a per-unit area (acre) tied to the adoption of a specific mitigation practice. This approach is similar to a number of land-based conservation programs in the United States, such as the CRP and The Environmental Quality Incentives Program (EQIP). This approach may economize on transaction costs because it relies on simple verification that the land-use change has occurred on the land in question, rather than quantification of the GHG tonnes that have been mitigated. The per-acre versus per-tonne issue is commonly referred to as "practice versus performance payments."

Scenario Description

Two of the carbon sequestration options considered thus far—afforestation and agricultural soil carbon sequestration (tillage change)—are evaluated because they represent the dominant mitigation activities at medium-high and low GHG prices, respectively, and they are distinct activities that can be tracked relatively easily at the per-acre level. Other activities may be more difficult to pay for on a per-acre basis, because they are not space extensive (e.g., CH_4 and N_2O mitigation activities assessed in Chapter 4).

Per-acre results are evaluated against the targeted \$15/tonne CO_2 payment scenario presented in Chapter 5 (i.e., the situation under which the selected activity—and only the selected activity—

receives payments at a rate of $15 per tonne). In the per-acre payment case, the activity and only the activity will receive payments of $100 and $15 per *acre* per year for the entire 10-decade simulation period for afforestation and tillage change activities, respectively. These per-acre values were selected because they roughly reflect the equivalent per-unit area payments of $15/tonne for representative sequestration rates for the two activities (about 6 to 7 t CO_2 per year for afforestation and 1 t CO_2 per year for tillage change).[3]

Two types of per-acre payment approaches are evaluated for each activity:

- **Uniform**—any and all acres within the United States that adopt the practice receive the same

Table 6-6: Qualitative Consideration of Implementation Issues for Selected Activities and Projects: Baselines, Additionality, and Reversal Risk

Activity	Baseline Setting Feasibility	Potential for Additionality	Reversal Risk of GHG Benefits (Permanence)
Afforestation	Credible baseline at adequate spatial and temporal resolution is likely. Involves observable land-use change.	High in most places within United States, unless locally high tree-planting rates.	Moderate if timber or land prices change or natural disturbances (fire, pests).
Forest management	Difficult to observe practices with remotely sensed data. Includes many practices varying by forest type, etc.	Likely need to demonstrate introduction of alternative practices.	Moderate if timber or land prices change or natural disturbances (fire, pests).
Protection (avoided deforestation)	Likely to require baseline deforestation rates by forest type and region, projected into future. Involves observable land-use change.	Likely high if new protection status is conveyed or high deforestation rates; low, if not.	Low if legal protection and it is enforced. High if susceptible to wildfire, has uncertain legal status, major commodity price changes, etc.
Agricultural soil carbon sequestration	Need data on continuous tillage practices and rates of alternative tillage adoption.	High if conventional tillage persists into future; low otherwise.	Moderate–high: potential seasonal tillage change (weed control); or change in crops or tillage practices in response to commodity prices or programs.
Agricultural CH_4 and N_2O mitigation	Remote sensing not useful. Need activity data per unit of production. If adequate data, likely credible baseline.	Moderate–high.	Low. No carbon storage subject to re-release involved.
Biofuel offsets	Similar to afforestation and soil tillage options but may require energy sector data to determine baseline demands for biofuels.	High based on recent market trends.	Low. Primary benefit does not involve carbon storage subject to re-release, although response to changing commodity prices could affect soil carbon.

[3] Note that the per-acre payment values were based on average carbon yields per acre nationwide but, as shown below, the realized gains per acre will be lower than average because of the inefficient nature of the incentive payments that either do not differentiate or differentiate imperfectly by carbon yield per acre.

per-acre payment for changing practices ($100 for afforestation and $15 for tillage change).

- **Productivity based**—any given acre receives one of five payment levels for each activity. The payments are based on the relative carbon productivity of the acre.[4]

By at least partly basing payments on carbon productivity, the productivity-based per-acre payments should operate more closely to per-tonne payments than uniform payments do. The productivity-based approach more closely follows programs such as the CRP, which have graduated payments for changes in land use and practices based on site characteristics. In contrast, the uniform payments should induce more inefficiency. The results below bear this out.

Per-Acre Payments for Carbon Sequestered through Afforestation

Results of the per-acre payments for afforestation are presented in Table 6-7 and compared to the $15 per-tonne afforestation-only payment scenarios from Chapter 5. The uniform $100 per-acre payment approach is substantially less efficient than the per-tonne approach. On an annualized basis over the projection period, the uniform per-acre payments generated only about 30 percent as much sequestration as payments on a per-tonne basis (41.9 vs. 137.4 Tg CO_2 Eq.). However, the value of the payments is about 60 percent as much ($790 MM vs. $1.36 billion). For the year 2015, which is the midpoint of the first decade of the simulation, only about one-quarter the amount of carbon is sequestered even though one-half as much acreage is afforested. This demonstrates a critical shortcoming of uniform per-acre payments, namely, that the payments are made without regard to the biophysical sequestration potential of the site—each afforested acre receives the same payment. Therefore, tonnes sequestered on a low productivity site are more costly than tonnes sequestered on a high productivity site, which is an economically inefficient way to sequester a given amount of carbon.

Table 6-7 shows how modifying the payments based on site productivity can improve the effectiveness of the per-acre payment approach. Productivity-based payments generate about 70 percent more carbon (annualized) than the uniform payments, although the cost of the payments rises by only about one-third. In the first decade (proxied by the 2015 results), the amount of carbon sequestered matches that in the dollar-per-tonne payment scenario. However, when compared

Table 6-7: Per-Acre vs. Per-Tonne Payment Approaches for Afforestation: 2015 and 2010–2110 Annualized

	Payment Scenario		
	$15/t CO_2 Eq.	$100/Acre Uniform	$100/Acre Productivity Based
Year 2015			
GHG mitigated (Tg CO_2 Eq. per year)	88.8	23.5	89.9
Net afforestation (MM acres)	10.1	5.1	11.3
Over 2010–2110 projection period (annualized)			
GHG mitigated through afforestation (Tg CO_2 Eq. per year)	137.4	41.9	68.6
Value of GHG payments (billion $ per year)	$1.36	$0.79	$1.06

[4] Candidate acres are ordered by carbon productivity and divided into quintiles. The middle quintile received the default value payment ($15/acre for tillage change or $100/acre for afforestation), the top two quintiles received higher per-acre payments, and the lowest two quintiles received lower per-acre payments. Payments were based on relative carbon productivity, yielding a payment range of $5 to $16 per acre for tillage change and $65 to $130 per acre for afforestation.

to the per-tonne results over the entire projection period, the productivity-based payment approach—although superior to the uniform payment approach—is still less efficient than the per-tonne approach in that it generates only half as much carbon on an annualized basis at a cost that is only about 22 percent lower. A payment approach that has more than the five differentiated payments employed here, however, would operate even more closely to the per-tonne approach.

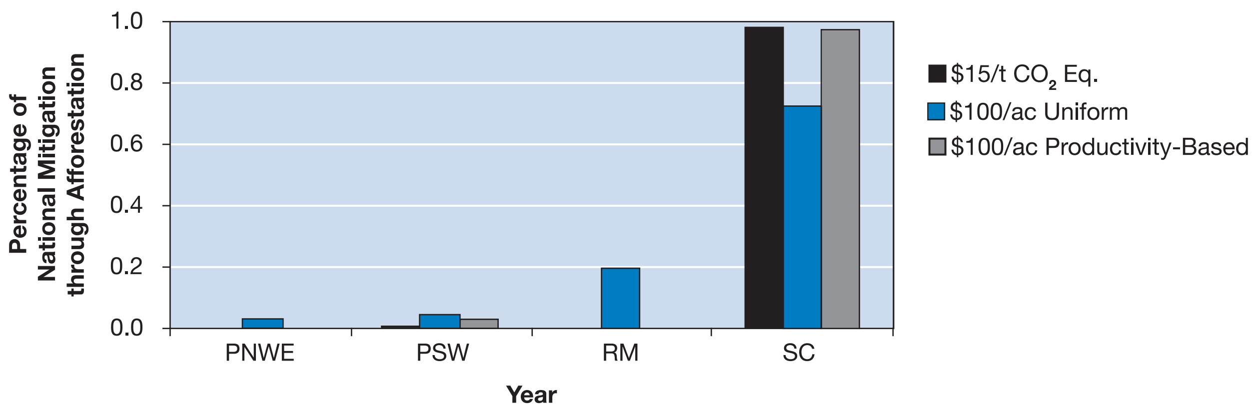
Changing the nature of the payments also changes the regional distribution of afforestation responses (see Figure 6-2). Under all payment approaches, the South-Central region has the largest afforestation response (over 70 percent of the national total); however, the uniform payment approach shifts some of the South-Central's afforestation carbon share to other regions, notably the Rocky Mountains. Again, this reflects the change in emphasis from paying for the highest carbon-yielding afforestation to paying for any afforestation at the same amount. The Rocky Mountains region's biophysical sequestration yield is less than the South-Central region's but receives the same payment and therefore comprises a larger share of the program under uniform payments than under per-tonne or distributed payments.

Per-Acre Payments for Agricultural Soil Carbon Sequestered through Changes in Tillage

Similar patterns emerge when comparing the per-tonne and per-acre payment approaches for agricultural soil carbon sequestration (see Table 6-8). As with afforestation, the uniform per-acre payment approach is substantially less efficient than the per-tonne or productivity-based payment approach. The uniform payments cost more than half as much as the per-tonne payments but yield only about one-fifth as much carbon. This result is similar to the findings of Antle et al. (2003), who find that per-acre contracts for soil carbon sequestration are up to five times as expensive as per-tonne contracts. As with afforestation, the inefficiency situation is partly remedied with the introduction of productivity-based payments, which generate more than half the amount of carbon at about 85 percent of the cost of the per-tonne approach.

The main factor underlying the inefficiency of uniform payments is found by looking at the distribution of tillage practices in the first decade (2015). The primary response under uniform payments is the adoption of conservation tillage, rather than the more substantial zero tillage practice. Farmers are paid the same for either practice and therefore adopt the less costly conservation tillage, even though it does not sequester as much carbon.

Figure 6 2: Regional Shares of Afforestation Carbon Sequestration by Payment Approach
Shares based on annualized mitigation, 2010 2100.

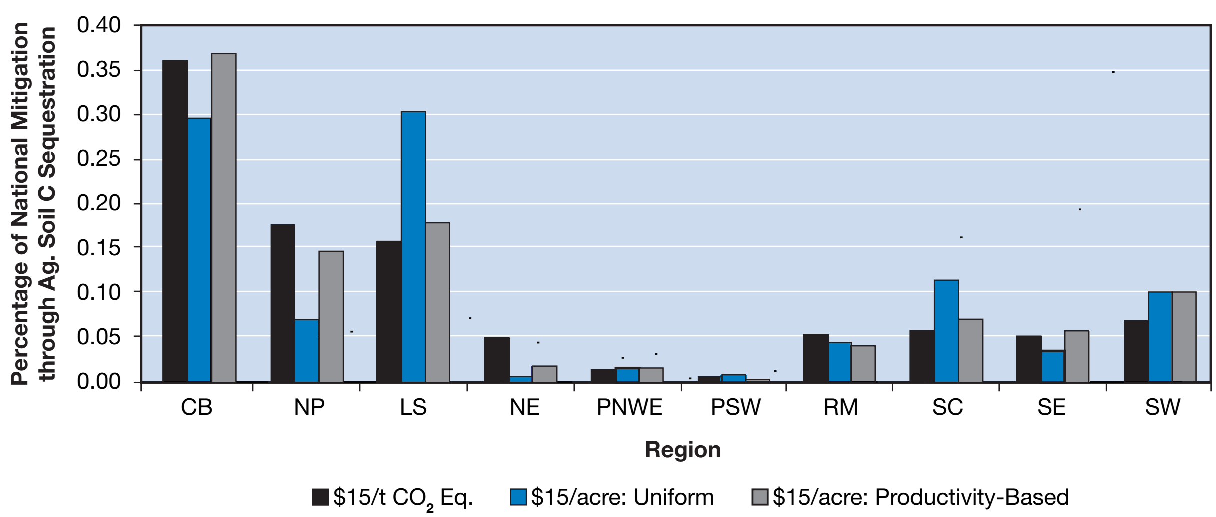


The regional distribution of agricultural soil carbon sequestration is also moderately affected by the payment approach (see Figure 6-3). Moving from per-tonne to a uniform per-acre payment, the regional shares shift some from the Corn Belt and Northern Plains to the Lake States and South-Central regions. Switching to productivity-based per-acre payments would restore the regional shares to a pattern roughly the same as the per-tonne payments.

Table 6-8: Agricultural Soil Carbon Sequestration Payment Approaches: 2015 and 2010–2110 Annualized

	Payment Scenario		
	$15/t CO_2 Eq.	$100/Acre Uniform	$100/Acre Productivity-Based
Year 2015			
GHG mitigated (Tg CO_2 per year)	190.9	41.9	127.7
Conservation tillage (MM acres)	2.9	119.5	0.2
Zero tillage (MM acres)	169.4	60.1	192.1
Over 2010–2110 projection period			
GHG mitigated through tillage change (Tg CO_2, annualized)	154.2	33.7	81.7
Value of GHG payments (billion $, annualized)	$1.61	$0.90	$1.36
Mitigation delivery efficiency			

Figure 6 3: Regional Shares of Agricultural Soil Carbon Sequestration by Payment Approach



CHAPTER 7

Non-GHG Environmental Co-effects of Mitigation

Chapter 7 Summary

Changes in land-use and management practices as a result of GHG mitigation actions can produce non-GHG environmental co-effects. Wide-scale conversion of agricultural land to forest may affect water quality, air quality, soil quality, and biodiversity. FASOMGHG predicts a net increase in forestland of 5 million acres at the \$15/t CO_2 Eq. (or \$55/t C Eq.) price and 58 million acres at the \$50/t CO_2 Eq. (or \$183/t C Eq.) price by the year 2055. All nonpoint source pollutant loadings to national waterways modeled in FASOMGHG, except pesticides, are predicted to decline from the baseline amounts under all GHG prices. Pesticides increase slightly under the low GHG prices but decline under the higher prices. Even at low GHG prices, these reductions in nonpoint source pollutant loadings may improve national and regional water quality, though effects would likely vary substantially across regions. Co-effects of GHG mitigation on biodiversity (not modeled in this analysis) may be both positive and negative. The net impact will depend on the baseline land cover and type of cover to which it is converted in response to GHG incentives.

This report mainly focuses on quantifying and evaluating the mitigation potential for net GHG emission reductions through forestry and agricultural activities. However, the large-scale changes in land use and land management practices projected in a number of the mitigation scenarios could have a substantial impact on resource flows in other (non-GHG) aspects of environmental quality. GHG mitigation co-effects in the forest and agriculture sectors include changes in water quality, air quality, soil quality, biodiversity, and aesthetics (McCarthy et al. 2001). Therefore, assessing the net societal effects of GHG mitigation will depend on more inclusive analysis that captures a range of expected effects within and across different impact categories (Elbakidze and McCarl 2004).

This chapter broadens the scope of the assessment by examining some key ancillary land-use and environmental effects that result from the forestry and agricultural activities and analytical scenarios described earlier. This report focuses on GHG effects as the primary objective, so the non-GHG environmental effects are reported here as ancillary. Conversely, many existing land-based programs are designed to attain non-GHG environmental objectives (e.g., erosion control, reduced nonpoint agricultural runoff, habitat preservation) but also may have GHG consequences. In that regard, GHG flows could be viewed as a co-effect of those programs. While assessing the general environmental effects of existing or proposed land management programs and their concomittant GHG benefits would be a way to estimate the latter, this approach remains outside the scope of this analysis.

Land Use

One of the key changes projected by the FASOMGHG model in most of the GHG mitigation scenarios is large-scale adjustments in land use and land management. As noted in Chapter 4, land tends to convert from agriculture to forests and biofuels in response to GHG price incentives, particularly under higher GHG prices. Underlying this general trend are numerous adjustments across the major land uses, namely cropland, timberland, pastureland, and land devoted to biofuels. For instance, at higher GHG prices, biofuels play an important role in GHG mitigation, and biofuel production uses substantial land area.

To get a sense for the overall adjustments projected by FASOMGHG, land uses are compared for the baseline, $15, and $50 constant GHG price scenarios for 2015 and 2055. (The $50 price is used here to evaluate the effect of higher prices on stimulating biofuel penetration, which is minimal at lower prices.) Under the baseline, crop and timberland use declines, while pastureland use increases. For the two GHG price scenarios, land use initially shifts heavily toward forests in 2015, as expected. For the $15 per tonne CO_2 scenario, timberland area increases 19 million acres, and for the $50 per tonne scenario, timberland area increases by 97 million acres by 2015. By 2055, however, much of this additional forest has converted out of timberland into other uses. Net timberland gain in 2055 for the $15 per tonne scenario is only about 5 million acres, and for the $50 per tonne scenario, it is around 58 million acres.

The results in Chapter 4 show that, as GHG prices rise, biofuels become a more important part of the future GHG mitigation portfolio. Table 7-1 illustrates the implications of that adjustment for land use. Large areas of land, 42 million acres, are ultimately devoted to biofuel production in the $50 per tonne CO_2 Eq. GHG price scenarios by 2055. Thus, although cropland and pastureland both decline relative to the baseline, this land converts to biofuel and forest uses.

Regional Distribution of Land Uses

Land-use changes projected to occur in response to GHG price scenarios are not evenly distributed. Figures 7-1 and 7-2 show the proportion of land in each region devoted to different land uses in 2015 and 2055 under the baseline scenario and the $15 and $50 constant GHG price scenarios. Three interesting trends emerge.

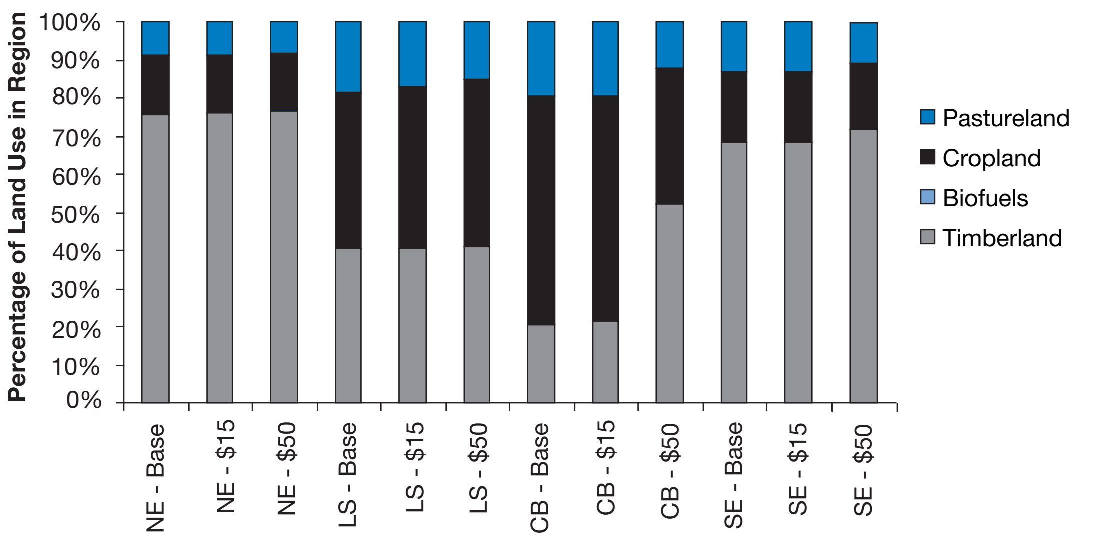
Table 7-1: Land Use under the Baseline, $15, and $50 (Constant) GHG Price Scenarios: 2015 and 2055
Quantities are in million acres.

	GHG Price Scenario ($/t CO_2 Eq.)		
Land Use	**Baseline**	**$15**	**$50**
2015			
Cropland	332	325	296
Pastureland	384	381	370
Timberland	333	352	430
Biofuels	0	0	1.4
2055			
Cropland	241	229	161
Pastureland	448	444	409
Timberland	303	308	361
Biofuels	0	4.5	42

Note: Land areas do not sum to the same value in each year because some uses are not included.

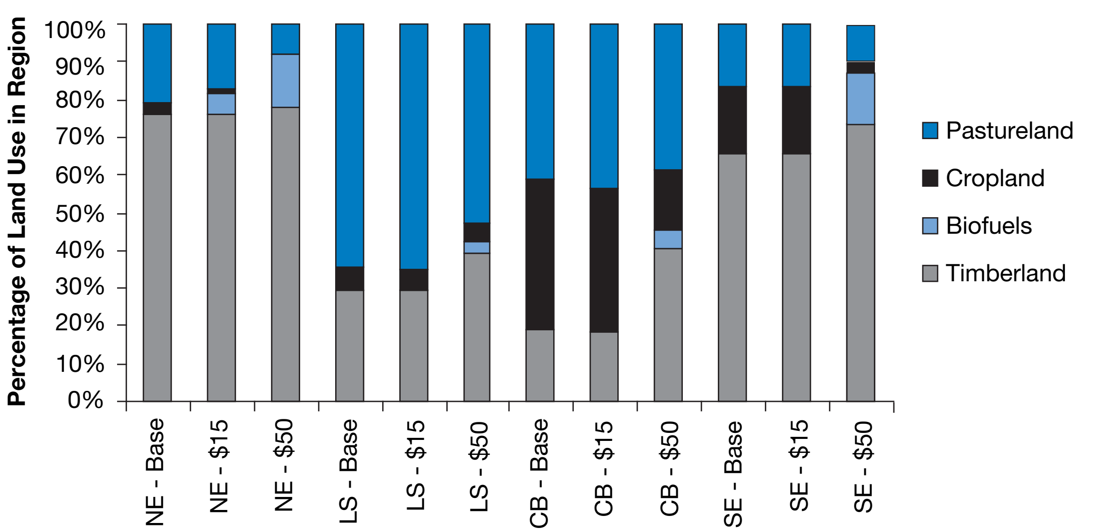
First, the proportion of land devoted to timber increases in the eastern United States with GHG prices. For higher GHG prices, the expansion of timberland is substantial in regions with less timberland initially, such as the Corn Belt. By comparison, in the western United States, the timberland proportion expands only slightly relative to the baseline. Most of this expansion

Figure 7 1a: Land Use Allocation by Eastern U.S. Regions in 2015: Baseline and the $15 and $50 Constant GHG Price Scenarios



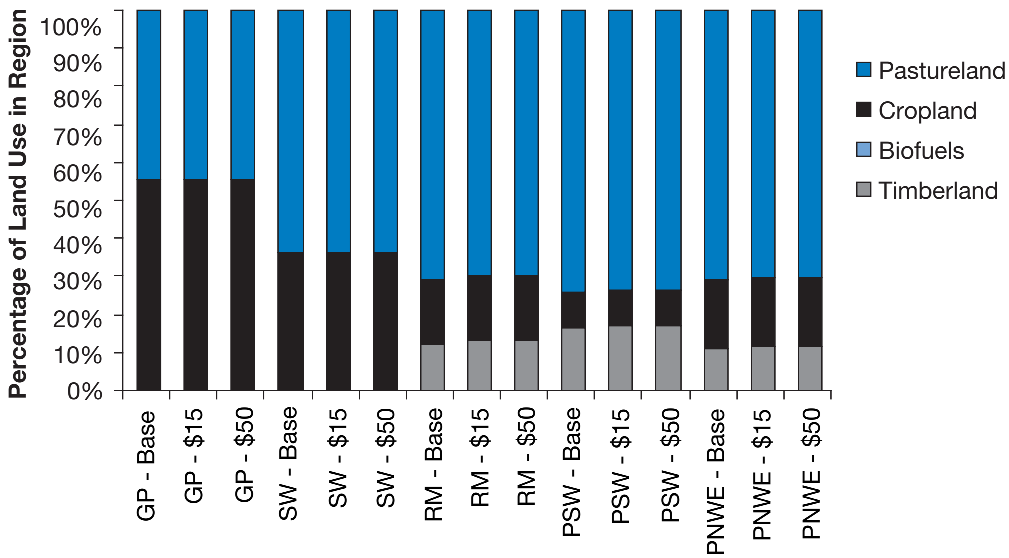
Notes: NE = Northeast; LS = Lake States; CB = Corn Belt; SE = Southeast

Figure 7 1b: Land Use Allocation by Eastern U.S. Regions in 2055: Baseline and the $15 and $50 Constant GHG Price Scenarios



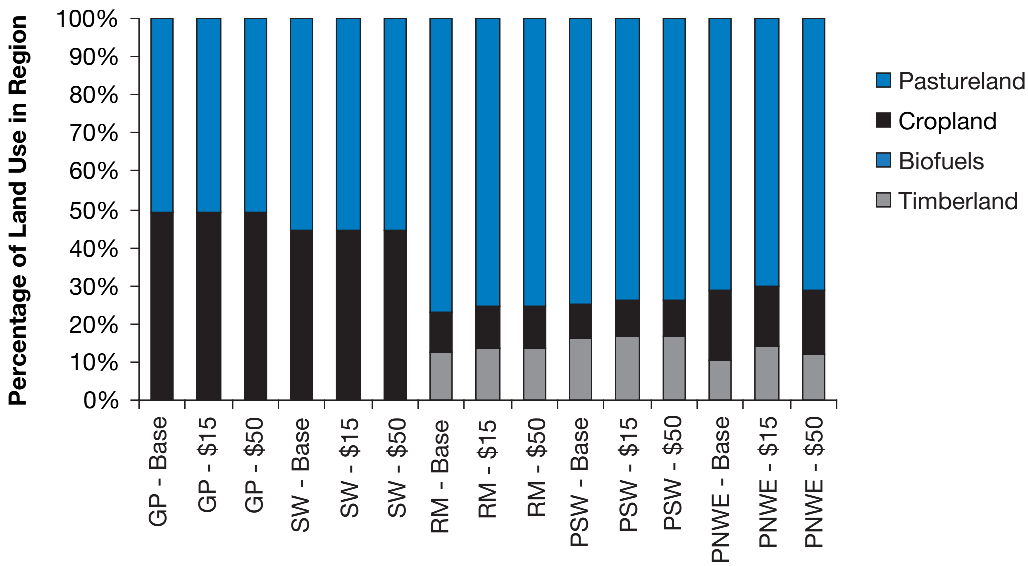
Notes: NE = Northeast; LS = Lake States; CB = Corn Belt; SE = Southeast occurs at the $15 GHG price, while for the larger $50 GHG price, there is little additional timberland expansion compared to the $15 GHG price scenario. These results generally make sense in that regions that already have substantial forest area (e.g., the Northeast) or regions that have few productive sites remaining for forests (i.e., many western regions) cannot substantially

Figure 7 2a: Land Use Allocation by Western U.S. Regions in 2015: Baseline and the $15 and $50 Constant GHG Price Scenarios



Notes: GP = Great Plains; SW = Southwest; RM = Rocky Mountains; PSW = Pacific Southwest; PNWE = Pacific Northwest, East Side of Cascades (Pacific Northwest West Side of Cascades is not shown due to a lack of data.)

Figure 7 2b: Land Use Allocation by Western U.S. Regions in 2055: Baseline and the $15 and $50 Constant GHG Price Scenarios



Notes: GP = Great Plains; SW = Southwest; RM = Rocky Mountains; PSW = Pacific Southwest; PNWE = Pacific Northwest, East Side of Cascades (Pacific Northwest West Side of Cascades is not shown due to a lack of data.)

increase timberland area with low or high GHG prices.

Second, cropland area declines in all regions over time under both GHG price scenarios, except in the Southwest (SW). There are fewer alternative uses for cropland in the Southwest region (i.e., fewer opportunities to plant trees and/or biomass crops) where more cropland is irrigated. Irrigation also makes less sense for alternatives such as biofuels or timber production.

Third, biofuels become a more important component of mitigation as GHG prices rise. Under the $15/t CO_2 Eq. constant GHG price scenario, only land in the Northeast is devoted to biofuels. Under a GHG price of $50 per tonne, however, over 40 million acres could be devoted to production of biofuels nationally by 2055. Regionally, all of this biofuel production occurs in the eastern United States (Figures 7-1a,b), since U.S. biofuel crops generally are rainfed and require fairly productive sites to be profitable with carbon prices. In most regions, the increases in biofuel production occur on cropland and pastureland, although in the Corn Belt, biofuel production occurs to some extent through conversion of timberland.

Timberland Management Intensity

Substantial changes in the intensity of forest management are underway in the United States, both in the baseline and in the mitigation cases. The forest industry historically focused on methods to extract large, old-growth trees in clear cuts up to the mid-twentieth century. Methods to establish and manage plantations began in earnest in the 1960s, and these efforts continue today.

The success of plantations and recent emphasis on other, noncommercial values of forests has shifted the focus in the last 20 years away from extracting old-growth through large-scale clear-cutting. The industry has shifted toward extracting smaller trees from fast-growing plantations and using alternative, less-intensive methods to extract timber from natural, second-growth stands with minimal forest damage.

The GHG mitigation scenarios explored in this study may influence trends in forest extraction (e.g., the intensification of plantation areas to generate more carbon sequestration). FASOMGHG model results suggest that GHG prices increase timberland management intensity to enhance carbon sequestration, via practices such as additional fertilizers to increase forest growth and thinning operations undertaken to enhance yield. Recent evidence from studies in the southern United States suggests that nitrogen fertilizing, chemical suppression of competition, and other management intensifications can increase biomass on sites from 6 to 20 percent (Siry 2002). With carbon valued for GHG mitigation purposes, the incentives for more intensive management could be heightened.

Agricultural Nonpoint Pollutant Runoff

One of the most important environmental issues facing agriculture in the United States is its contribution, along with forest management and urban development, to nonpoint source water pollution. Nonpoint sources, particularly agriculture, are considered to be the leading source of water quality impairment in U.S. rivers, lakes, and streams (EPA 2000). Siltation, nutrient runoff (such as nitrogen and phosphorous), and pesticides are the primary nonpoint water pollutants from agriculture.

This section of the report focuses on four of the most important runoff components from agriculture: nitrogen, phosphorous, sediments, and pesticides. Individual estimates of inputs or loadings of these pollutants are shown for several GHG price scenarios. For nitrogen and phosphorous, loadings are estimated using algorithms from the EPIC model (Williams et al. 1989) imbedded in FASOMGHG. For soil erosion, the outputs are total soil erosion, based on the Modified Universal Soil Loss Equation (MUSLE). It is not possible here to quantify direct pesticide loadings (field outputs). Therefore, changes in pesticide use are presented to approximate loadings potential.

The substantial changes in land use and management projected under some of the GHG mitigation scenarios in Chapter 4 suggest there could be large potential changes in water quality. First, there is potential to reduce nonpoint source pollution through land-use change, such as shifting land out of agriculture and into forests, and establishing perennial biofuel cover. Both forestry and biofuel production typically use fewer inputs and produce fewer pollutants than traditional crop agriculture. Management inputs (chemical and mechanical) in forestry are applied less frequently and less intensively than in agriculture. There is less experience in and information on pollutants arising from biofuel production. The FASOMGHG model, however, does include nutrient and pesticide requirements as part of the production set for biofuels.

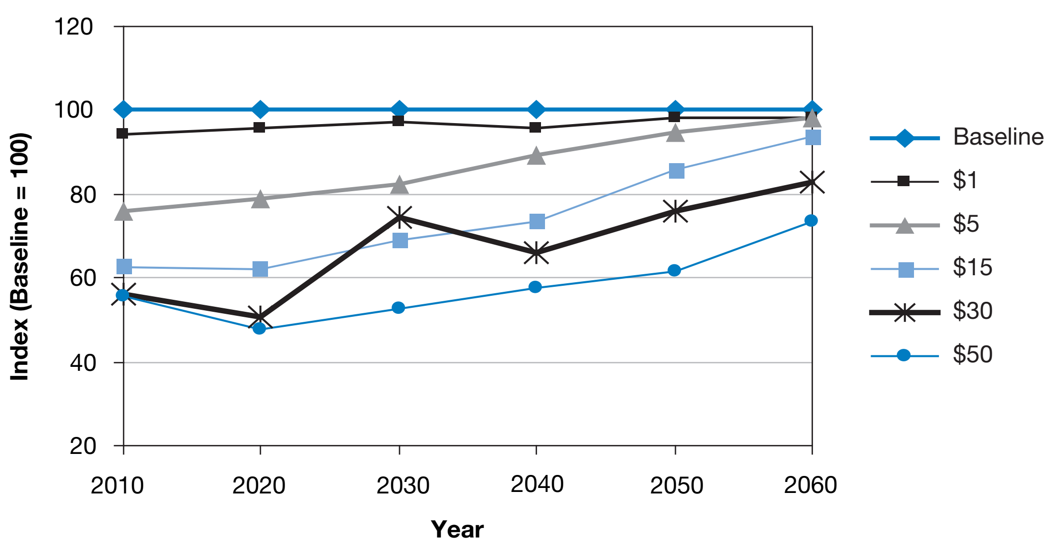
Second, changes in the management of agricultural land could alter the magnitude and quality of farm runoff. Adoption of conservation tillage was originally developed to reduce soil erosion; thus, adoption of conservation tillage to increase soil carbon should reduce sediment lodgings from soil erosion over time. Because phosphorous is typically attached to soil particles, reductions in soil erosion should also reduce phosphorous entering rivers and streams.

The potential effect of conservation tillage on nitrogen and pesticide runoff, however, is less clear. Pesticide use often increases with the adoption of conservation tillage (because of the need for greater weed and other pest control), and conservation tillage reduces yield for certain important crops, such as corn. Consequently, farmers may adjust by adopting more intensive nitrogen and pesticide applications when they adopt conservation tillage. Agricultural soil management practices to mitigate N_2O emissions by reducing fertilizer use also have the joint benefit of reducing nitrogen loadings.

The rest of this section looks more carefully at the estimates provided by FASOMGHG for soil erosion, phosphorous, nitrogen, and pesticides. Each of the variables is evaluated relative to its projected baseline level, normalized to a value of 100 for the purpose of cross-pollutant comparisons over time, and across the range of constant GHG price levels evaluated in Chapter 4.

Adoption of reduced tillage practices induced by the GHG prices reduces soil erosion (Figure 7-3). Soil erosion reductions occur relatively quickly, due mainly to rapid adoption of tillage change and shifts in land from agriculture to

Figure 7 3: Soil Erosion Index over Time by (Constant) GHG Price Scenario (Baseline = 100)



forestry (i.e., over the first 10 to 20 years of the model run). Over time, erosion levels gravitate slightly back toward baseline levels. But these erosion reductions produce annual benefits, implying continuing improvements in water quality over time. Baseline levels of erosion are also declining over time, so that all of the paths shown in Figure 7-3 represent net reductions in erosion relative to today.

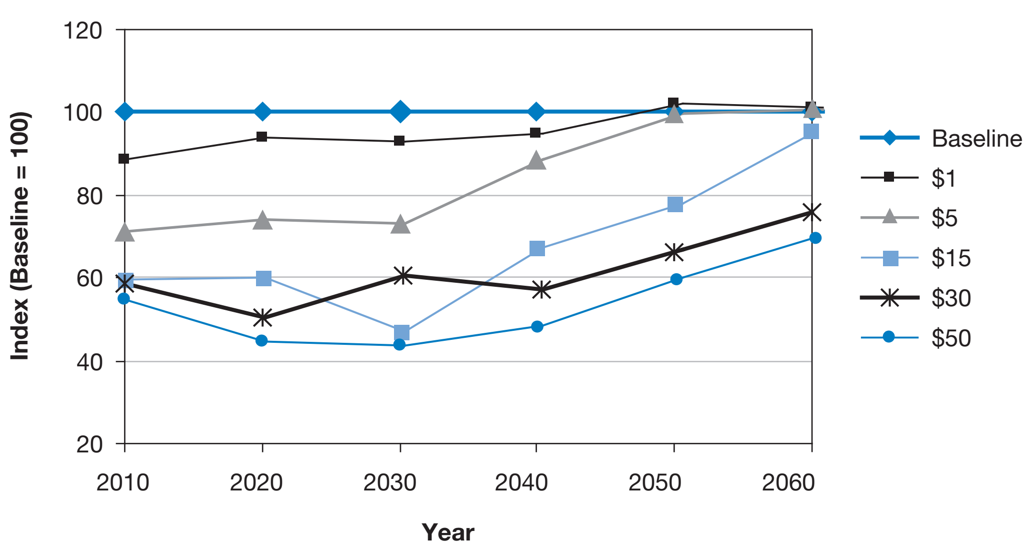
Estimated phosphorous loadings decline with the introduction of GHG prices (Figure 7-4). This decline is roughly proportional to the reductions in erosion, because phosphorous is attached to soil particles. For higher GHG prices in the range of $15 to $50, the reductions in loadings in the initial period are roughly similar, suggesting the maximum reduction in phosphorous may be around 40 percent. In many cases, loadings begin moving back toward baseline levels over time as farmers increase inputs per hectare to make up for yield losses associated with conversion to conservation tillage. Loadings remain lower than baseline levels in total, because overall cropland areas tend to decline with GHG pricing.

Estimated nitrogen loadings decline in all scenarios (Figure 7-5). These reductions, as a percentage of baseline loadings, are smaller proportionally than those for phosphorous and erosion. The initial reduction ranges from 5 to 21 percent under the GHG price scenarios considered. For the lower GHG prices, reductions in nitrogen loadings initially are relatively small, and loadings move back toward baseline levels over time. For the higher GHG prices (>$15 per tonne CO_2), reductions in loadings are larger initially, but, after a while, they begin to rise back toward baseline levels.

The increase in nitrogen applications is in response both to lower crop yields associated with conservation tillage and to higher crop prices. Under the higher price scenarios, farmers in the FASOMGHG model are shown to intensify the use of nitrogen to increase overall production of crops on land that remains in agriculture, and that increase eventually leads to increased loadings over time but still below baseline levels.

Pesticide applications increase relative to the baseline for lower GHG prices (Figure 7-6), as land shifts into conservation and zero-tillage practices. With reduced tillage, farmers often increase pesticide use to control for weeds, pests, and other competition in lieu of mechanical control through conventional tillage practices. These increases result in greater overall pesticide

Figure 7 4: Phosphorous Loading Index over Time by (Constant) GHG Price Scenario (Baseline = 100)



releases under the low-price GHG scenarios. As GHG prices rise, however, more land is converted from agriculture to forestry and biofuels, and aggregate pesticide applications and runoff are projected to decline.

Changes in Agricultural Runoff and Water Quality—Results from a Separate Case Study

Measuring the impacts of these nonpoint source pollution outputs on ambient water quality levels requires additional modeling. The relationship between nutrient or soil runoff and water quality is a complex one, and linking the loading results described above to environmental outcomes is difficult. The actual effects of changes in agricultural runoff on water quality will depend on numerous factors, including existing loads, assimilative capacity, routing of the pollutants through the river and stream network, and nutrient processes in the water (including nutrient limitations), all of which vary substantially from watershed to watershed.

Figure 7 5: Nitrogen Runoff Index over Time by (Constant) GHG Price Scenario (Baseline = 100)

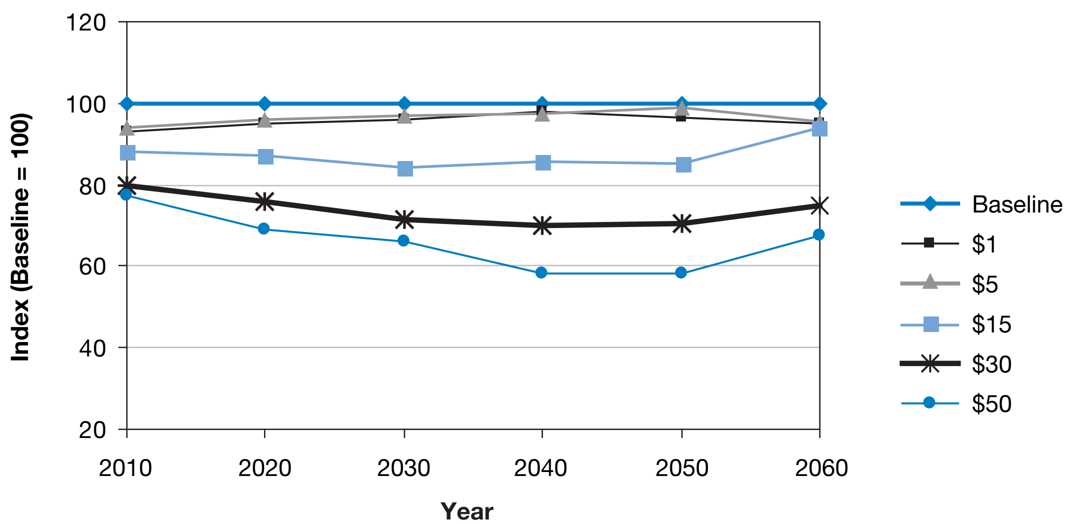
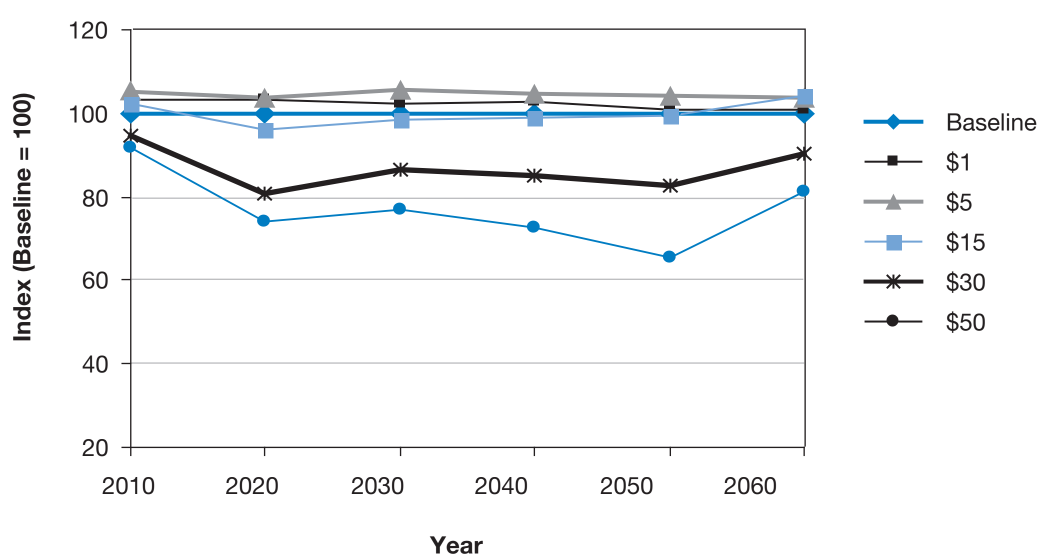


Figure 7 6: Pesticide Index over Time by (Constant) GHG Price Scenario (Baseline = 100)



This section describes a previously conducted case study to show water quality impacts associated with GHG mitigation in agriculture, using a related economic model linked to a water quality model. Note that the case study is from a separate analysis described in Pattanayak et al. (2005) and is not directly a part of the GHG mitigation scenarios performed for this report. However, because the modeling framework and scenarios are so similar between this study and Pattanayak et al., it warrants further discussion here.

The case study linked ASMGHG (McCarl and Schneider 2001), which is in essence the agricultural component of the FASOMGHG model used in this report, with the National Water Pollution Control Assessment Model (NWPCAM), a model developed by RTI International (Research Triangle Institute) for EPA.

NWPCAM was used to estimate regional and national water quality impacts of GHG mitigation scenarios of $6.80 and $13.60 per tonne of CO_2 ($25 and $50/t C, respectively), run through ASMGHG. Similar to scenarios analyzed in this report, GHG mitigation actions taken in ASMGHG include afforestation, agricultural soil carbon sequestration through tillage changes, CH_4 and N_2O reductions through livestock and soil management changes, and biofuel production.

One benefit of the NWPCAM model is that it provides results on water quality outcomes through a water quality index (WQI) that accounts for the loading of different pollutants, as well as the impacts of those pollutants in specific stream segments. The WQI is on a scale from 0 to 100 and was developed for NWPCAM based on work by Vaughn (1986) and McClelland (1974).

A second benefit is that the NWPCAM model projects stream impacts throughout the country, allowing both for highly aggregate weighted measures of water quality at the national and regional levels, as well as for more spatially refined results within regions.

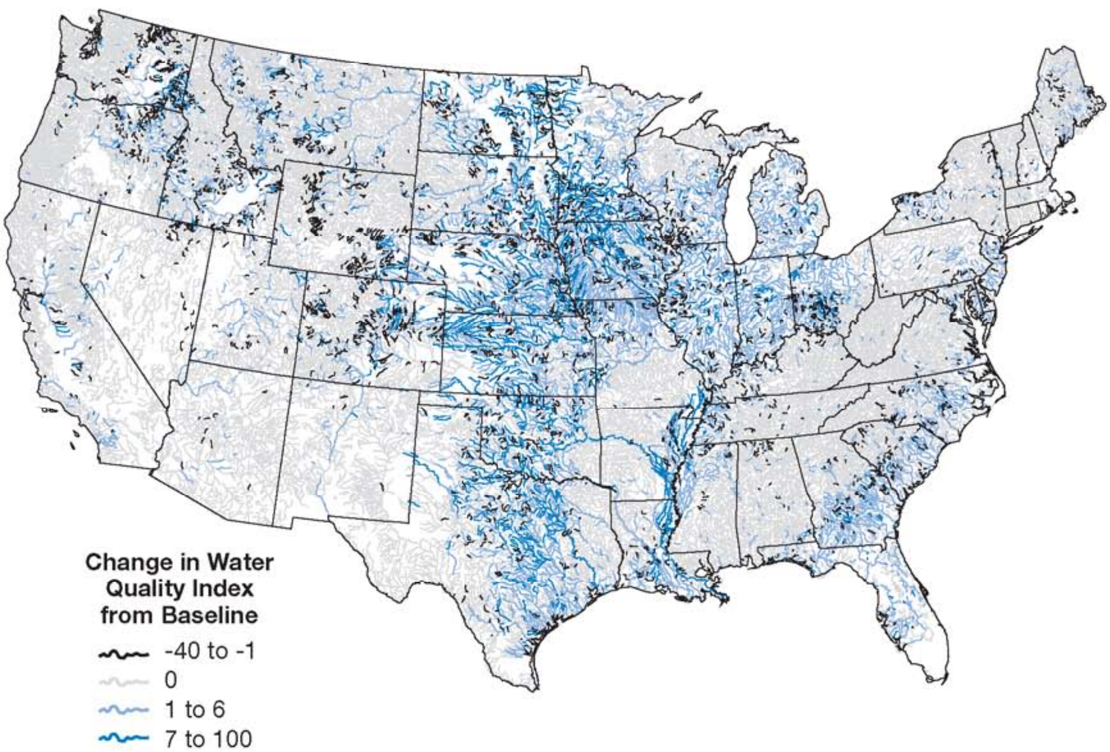
Results for the $6.80 CO_2 Eq. price scenario showed, among other things, that CO_2 makes up most of the net GHG mitigation, a decline of cropland production using conventional tillage, an expansion of conservation tillage, and an increase in afforestation of 5.8 million acres.

Figure 7-7 shows the water quality implications of the $6.80 per tonne CO_2 Eq. scenario distributed across the continental United States. The water quality changes reflect changes in loadings for all GHG mitigation activities, except for afforestation and livestock management. Note also that ASMGHG and NWPCAM are both static models, so the simulated water quality effects in Figure 7-7 are for a representative year (circa 2020, based on data inputs to the models used). Dark blue indicates substantial improvement in surface water quality, light blue presents small to moderate improvement, black spots indicate some water quality degradation, and grey areas reflect no appreciable change in water quality. For this relatively low GHG price, the aggregate, national-level surface WQI in NWPCAM increases by about 1.5 index points, which is a 2 percent improvement in the WQI from its baseline levels. Effects are primarily concentrated up and down the Mississippi River Valley and west of the 100th meridian.

Nitrogen loadings into the Gulf of Mexico are projected to decline by 144,000 tonnes per year under this price scenario. *This decline amounts to about half of the national goal under the Watershed Nutrient Task Force for solving the hypoxia problem* (Mississippi River/Gulf of Mexico Watershed Nutrient Task Force 2001). These results are generally consistent with those shown in modeling of Gulf nitrogen loadings by Greenhalgh and Sauer (2003), although that study used different economic and biological models.

The changes vary across regions. Focusing on the Corn Belt and Southeast regions, as well as the nation as a whole, Table 7-2 shows the effects of the $6.80 per tonne CO_2 Eq. GHG price scenario for the ASMGHG-NWPCAM simulation. The national effects are consistent with the results for the FASOMGHG model described above, although total suspended solids increase nationally in the case study. Loadings decline in the Corn Belt region, because large areas of cropland are converted to conservation tillage. In contrast, loadings increase in the Southeast, mainly because there are adjustments in the types of crops grown. Despite this increase in loadings, the WQI for the Southeast improves very slightly. As noted above, the link between loadings and water quality outcomes depends on numerous location factors. Even within the Southeast, some regions experience lower loadings and water quality improvements.

Figure 7-7: Changes in Water Quality from Soil Carbon Sequestration and Other Agricultural Management Changes under $6.8 per Tonne CO_2 Scenario in ca. 2020, using the ASMGHG-NWPCAM Integrated Agriculture Water Quality Model



Note: $6.80/t CO_2 Eq. = $25/ t C Eq., the modeled price.

Source: Pattanayak et al. (2005).

Table 7-2: Change in Pollutant Loadings for Selected Agricultural Pollutants and the WQI for the $6.80 per tonne CO_2 Eq. Scenario, using the ASMGHG-NWPCAM Model Integration

	% Change in Pollutant Loading or WQI		
	Corn Belt	**Southeast**	**National**
Pollutant Loadings			
Nitrogen	–2.4	1.3	–3.1
Phosphorous	–0.7	0.3	–2.0
Total suspended solids	–2.4	0.2	0.5
Pesticides	–0.1	1.7	0.9
WQI	4.5	0.7	2.0

The improvements in these locations lead to aggregate gains in water quality at the regional level as loadings shift to areas that are less damaging to water quality.

The Pattanayak et al. ASMGHG-NWPCAM study suggests that, even for low GHG prices in the range of $5 to $15 per tonne CO_2, national-level water quality will improve. *At around $5 per tonne of CO_2, this improvement could be around 2 to 3 percent for the nation and over 4 percent for the Corn Belt*, relative to baseline WQI measures.[1] The benefits occur heavily in the middle part of the country, as Figure 7-7 and Table 7-2 indicate, because the most intensive agricultural crop production currently occurs there.

Lastly, the reduction in nitrogen outputs specifically could benefit an emerging national water quality issue, hypoxia in the Gulf of Mexico.

Implications for Biodiversity of GHG Mitigation

Analysis of the impacts of GHG mitigation programs on biodiversity has gained substantial attention recently. Generally, increasing forest area restores habitat for plant, aviary, and soil organisms. It reduces forest fragmentation and connects protected-area and habitat fragments by providing corridors for seasonal or opportunist movement of broad-ranging species with large home range requirements (Wayburn et al. 2000; Franklin and Forman 1987; Mladenoff et al. 1997; Peters and Lovejoy 1992).

Huston and Marland (2003) and Gitay et al. (2002) suggest that there could be both positive and negative effects of terrestrial carbon sequestration programs on biodiversity, depending on the location. For instance, biofuel projects that remove natural forest cover and replace it with monocultural vegetation could reduce biodiversity locally. Alternatively, restoring bottomland hardwoods on agricultural lands in the southeastern United States would return that part of the landscape closer to its presettlement ecosystem and could thereby increase biodiversity on a local and regional scale. Huston and Marland (2003) and Gitay et al. (2002), however, do not attempt to quantify biodiversity impacts and mostly consider local effects.

Assessing the net effects of GHG mitigation on biodiversity is complicated. Plantinga and Wu (2003) explore carbon management through afforestation in Wisconsin and find that a scenario that increases forest area by 25 percent would cost $100 to $132 million to accomplish. Their findings also indicate that this scenario would provide additional consumptive and nonconsumptive wildlife benefits of $61 million. Their study, however, assumed that the new forests would be similar to existing forests (i.e., landowners would not adjust the species types to maximize carbon payments) and that the forests would be managed in the same fashion that forests are currently managed. This result contrasts with other studies that argue that carbon sequestration payments could lead to suboptimal biodiversity outcomes (Caparros and Jacquemont 2003).

Clearly, GHG mitigation activities can influence biodiversity in positive and negative ways. The remainder of this section focuses on results from the FASOMGHG model scenarios that can provide some insight into these potential impacts.

Several forest-sector trends in the FASOMGHG results have potential implications for biodiversity. One trend is that the GHG price scenarios imply that more intensive management is aimed at increasing the growing stock of timber and carbon. Increasing the area of plantations is one such intensification. Tree planting now occurs on more than 2 million acres per year in the United States (Haynes 2003), and planted pine occupies just over 30 million acres of the land base (almost one-fifth of the U.S. South's timberland base). In the future, the area of planted pine is expected to rise by a factor of two-thirds by 2040, without considering

[1] Regional WQI measures in NWPCAM are aggregated weighted averages of the WQI for each stream reach in the region, weighted by the mile frontage of each reach.

GHG prices (USDA Forest Service 2002). With GHG pricing incentives, the area is projected to expand even more.

If the additional plantations resulting from GHG mitigation are planted on marginal or abandoned agricultural land, these plantations likely will improve biodiversity relative to current conditions. If, instead, the plantations are substituted for natural stands and managed in strict even-aged rotations, these plantations could reduce biodiversity relative to the natural stands they replace, as argued by Huston and Marland (2003). Some afforestation of marginal cropland in the Mississippi Alluvial Valley, however, uses a mix of native bottomland hardwood species to enhance biodiversity and restoration of native ecosystems (e.g., Schlamadinger [2003]).

The overall area of timberland is expected to increase under the GHG scenarios, suggesting that new lands planted to trees will be planted on lands that are currently agricultural. Conversion of intensively cultivated agricultural lands to forest cover, even a monocultural forest cover, is likely to have positive—or at least nonadverse—effects on biodiversity.[2] Forest edge effects and the juxtaposition of different habitats, and corridors for species movement are enhanced (Wayburn et al. 2000; Peters and Lovejoy 1992).

Thus, it is likely that the new forests projected by FASOMGHG will improve biodiversity relative to maintaining agriculture. In addition, the FASOMGHG model projects that forests will be managed in longer rotations when GHG price incentives are introduced. Longer rotations imply less-intensive harvesting regimes (and less forest and soil disturbance) and likely improved biodiversity. It is difficult to know with certainty which of these effects will dominate—intensive monoculture or expanding timberland area combined with less-intensive management on some land. The results of the scenarios explored in this report raise questions, however, which should be addressed in further research.

In addition to the forestry-biodiversity interaction, other changes suggested by the results in this report have biodiversity implications. As GHG prices rise above $15 per tonne CO_2, the results in this report suggest that biomass energy becomes a competitive option for mitigation, and the area of land devoted to producing biomass crops expands. Huston and Marland (2003) state several concerns about the implications of using land for biomass production and potential reductions in biodiversity if this land involves removing natural timberland cover, wetlands, or other natural areas. If land devoted to biomass energy production involves converting cropland to biomass, however, biodiversity could increase.

Thus, the impacts of growth in biomass energy production on biodiversity will depend on which lands are converted for use. Given the aggregate nature of the FASOMGHG model, it is difficult to determine exactly what parcels of land will be converted to biomass production, so this report does not attempt to quantify these potential impacts. However, biodiversity issues related to biomass will become more important as carbon prices rise, given the potential penetration of biomass energy at the higher levels.

A final consideration relates to agricultural production. The results in the model imply substantial conversion to conservation and zero tillage, particularly at the lower GHG prices. Conservation tillage improves the health and diversity of the soil ecosystem (Lal et al. 1998) and would be expected to improve soil quality indicators substantially at the lower carbon prices. However, conservation tillage often also involves increasing inputs, such as chemical fertilizers and pesticides, which could offset some of the environmental gains from conservation tillage.

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[2] Conversion of native grasslands to tree plantations, however, could diminish unique prairie ecosystems (Gitay et al. 2002), but this type of conversion is not expected to occur under the mitigation strategies analyzed in this report.

CHAPTER 8

Summary of Insights on Key GHG Mitigation Issues

This chapter concludes the report by showing how the results of the analyses presented in the previous chapters may have relevance for key issues regarding GHG mitigation from the forest and agriculture sectors.

Key Issues

Some key issues for GHG mitigation in forestry and agriculture are described below.

Level of Mitigation Achieved. *How much GHG mitigation is sought from the forest and agriculture sectors?* This report evaluates forestry and agriculture's potential to sequester carbon and reduce GHG emissions under different scenarios. As higher levels of mitigation are achieved, the portfolio of activities expands, as does the cost of mitigation.

Time Frame. *When would the mitigation occur?* This is a particularly critical question for carbon sequestration activities, which have complex time dynamics. Sequestration can generate substantial mitigation in the near to middle term (1 to 3 decades) but can decline after that because of biophysical saturation and practice reversal. Some alternatives such as biofuels have great technological potential to mitigate GHGs immediately and over the long term, but the infrastructure to handle widespread adoption could take decades to develop.

Comprehensiveness of Scope. Analytical results show that nearly 2,000 Tg CO_2 Eq. (or 2 billion tonnes) per year of mitigation potential exists at the highest-price scenario evaluated ($50/tonne CO_2 Eq.) if all private land, activities, and GHGs are included. However, this rather large mitigation potential can be reduced via criteria that narrow the activities, GHGs, and time frames considered.

- *Which activities and GHGs are included?* Inclusion could range from essentially all activities in forestry and agriculture that have some measurable GHG impact to a select few activities or GHGs that are targeted for their cost-effectiveness, desirable co-effects, or ease of monitoring.
- *What land base is included?* The analysis in this report has examined the mitigation potential from all private lands in the conterminous United States. But the scope could in principle be larger or smaller than that. For instance, public land can be managed to sequester carbon and otherwise mitigate GHGs, but these actions would presumably need to operate outside the type of economic incentive-based system evaluated in this report. Furthermore, programs may focus on specific regions or states either for economic or jurisdictional reasons.

Incentive Structure. The incentive structure refers to the form that the GHG mitigation incentives take and the appropriate incentive level for a given mitigation quantity. Related questions include the following:

- *What are the units of exchange?* For land-based actions, a critical question is whether payments are based on a per-tonne of CO_2 Eq. or per-acre basis. Although the latter is less costly to measure, monitor, and verify (MMV), the former tends to be much more efficient.

- *What mechanisms can be used to induce mitigation actions?* In a purely market-based system, mitigation incentives are determined by the laws of supply and demand. In a government-sponsored incentive program, compensation levels may be administratively determined.

Accounting Requirements. *How will GHG mitigation performance be measured?* Related questions include the following:

- *Are GHG mitigation quantities measured at a specific point in time, an average over some time period, or cumulatively since the beginning of the program?* The amount attributed to an action can be substantially affected by the completeness of the accounting over time.
- *Will adjustments be made to revise project-level mitigation totals?* Ideally, project quantification should reflect net mitigation over time. This suggests that adjustments may be necessary to capture baseline emission or sequestration levels that would have occurred without the project, GHG effects induced outside the project boundaries (leakage), and future carbon reversal likely to occur after a project ends.
- *Will non-GHG co-effects be included in mitigation evaluations?* The report has shown that mitigation actions may produce environmental co-effects that could influence the desirability of GHG mitigation strategies. If possible, should these co-effects be quantified and thereby modify the attractiveness of certain mitigation options?

Infrastructure. *What infrastructure or technical assistance might be helpful or necessary for landowners to realize potential mitigation opportunities?* Standardized and widely available measurement, monitoring, and verification guidelines and methods, for example, may help landowners overcome implementation barriers and engage in mitigation activities.

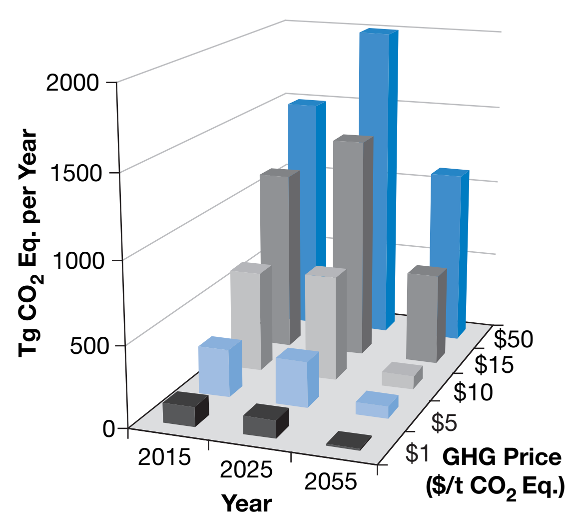
Insights from Analyzed Results

With these fundamental issues in mind, the results of the analyses throughout this report are used to provide insights that could shed light on the potential role of forestry and agriculture in GHG mitigation. These insights are enumerated and discussed below.

While national mitigation rates decline over time (under constant price scenarios), cumulative GHG mitigation steadily increases.

Total national mitigation—under the scenario with a constant GHG price of \$15/t CO_2 Eq. (\$55/t C Eq.)—is estimated to average almost 630 Tg CO_2/yr (172 Tg C) in the first decade, 655 Tg CO_2/yr (179 Tg C) by 2025, and decline to 86 Tg CO_2/yr (23 Tg C) by 2055 (see Figure 8-1). The total range of constant price scenarios evaluated is \$1 to \$50/t CO_2 Eq. (\$3.7 to \$184/t C Eq.). A declining rate of *annual* mitigation (i.e., occurring in a given year) over time is the result of saturating carbon sequestration (to a new equilibrium) in forestry and agriculture and carbon losses after timber harvesting.

Figure 8 1: National GHG Mitigation at Three Focus Dates by GHG Price: Average Annual



Cumulative GHG mitigation (i.e., achieved in the years up to a given year) for the $15/t CO_2 Eq. and other constant price scenarios steadily increases (see Figure 8-2). This cumulative amount reaches about 26,000 Tg CO_2 (7,080 Tg C) by 2055. On an *annualized* basis over 100 years, the $15/t CO_2 Eq. scenario generates 667 Tg CO_2/yr (182 Tg C) in GHG mitigation relative to the projected baseline. Annualized results represent the net annualized equivalent, or "annuity value," of all GHG mitigation over the entire 100-year period of analysis, using a discount rate of 4 percent.

Identifying attractive activities may require looking at a range of characteristics for each option.

Each potential mitigation activity has a wide range of characteristics that may make it more or less desirable. Table 8-1 highlights some of the key characteristics of each mitigation activity considered in this report: mitigation potential, regionality, non-GHG co-effects, and reversal risk. Reversal risk is particularly important if the action is expected to be short-lived and liability provisions are not in place to ensure that post-program reversal is addressed. Other potentially important considerations not included in this table (and not explicitly modeled in this report) include issues such as the difficulty of measuring, monitoring, and verifying project-level GHG effects and setting project baselines.

The quantity and timing of mitigation can determine the selected activities.

Table 8-2 shows that modest mitigation quantities (less than 300 Tg CO_2 Eq. per year) may be achieved in the near term, with activities that primarily include agricultural soil carbon and forest management, at less than $5/t CO_2 Eq. More ambitious levels require a different range of activities (e.g., afforestation and biofuels) and require $15 to 30/t CO_2 Eq. and above. Long-term mitigation requires permanent reductions in CO_2 and non-CO_2 emissions from agricultural practices (achievable at a relatively low GHG price incentive) and biofuel production. Biofuels are economically achievable only at the higher GHG prices and in the longer run, primarily because of capacity constraints on biofuel use in the short run.

Achieving a specific mitigation level within a narrow time frame may shift emissions to periods before and after the period of interest.

The report examines scenarios in which an average annual mitigation quantity is set for Year 2025 (the midpoint of the decade 2020 to 2030), which is

Figure 8 2: Cumulative GHG Mitigation in Tg CO_2 Eq.

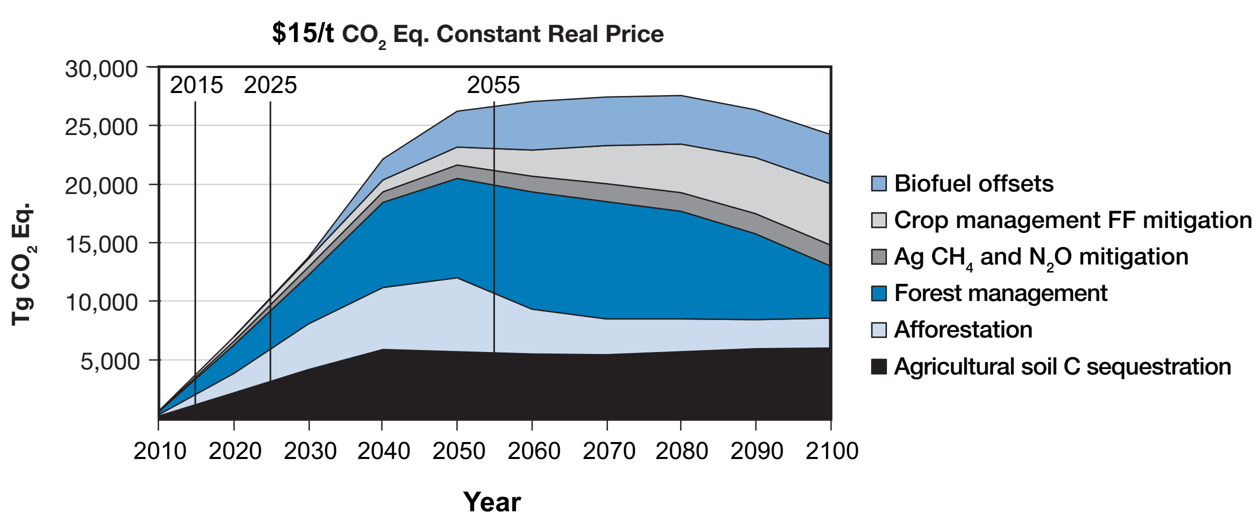


Table 8-1: Characteristics of GHG Mitigation Activities

Activity	GHG Mitigation Potential[a]	Regions of Emphasis	Key Environmental Co-effects	Reversal Risk[b]
Afforestation	High	South-Central and Corn Belt	Increases forest cover; improves water quality; biodiversity effects either (+) or (-) depending on characteristics of new forests and ecosystem displaced by new forests.	High
Forest management	Moderate	South-Central Southeast	Enhances forest biological stock; longer rotations can provide critical habitat.	High
Agricultural soil carbon sequestration	Moderate-low	Corn Belt Lake States Great Plains	Reduced erosion and nutrient runoff. Small increase in pesticide use.	Moderate-high
Fossil fuel mitigation from crop production	Low	South-Central and Southwest	Negligible effects within forest and agriculture sectors.	Low
Agricultural CH_4 and N_2O mitigation	Low	Corn Belt	Air quality improvements from some activities (e.g., manure management).	Low
Biofuel offsets	Very high	Eastern regions	Biodiversity effects depend on previous land use	Low

[a] Mitigation potential refers to mitigation attained at the highest GHG prices evaluated in report scenarios.

[b] Individual activities or projects could have lower or higher reversal risk, depending on activity and site characteristics.

Table 8-2: Potential Implications of Mitigation Level and Time Frame

Mitigation Quantity (Tg CO_2 Eq./year, annualized, 2010–2100)	GHG Scenario ($/t CO_2 Eq.)	Primary Near-Term Strategies (By 2025)	Primary Long-Term Strategies (Beyond 2025)
Low (<300)	$1–$5	Agricultural soil carbon sequestration	Forest management
		Forest management	Emissions reduction (CO_2 and non-CO_2) from agricultural activities
Medium (~300–1,400)	$5–$30	Afforestation	Forest management
		Forest management	Biofuels
High (1,400+)	$30+	Afforestation	Biofuels
		Forest management	Fossil fuel CO_2 and non-CO_2 emission reduction options

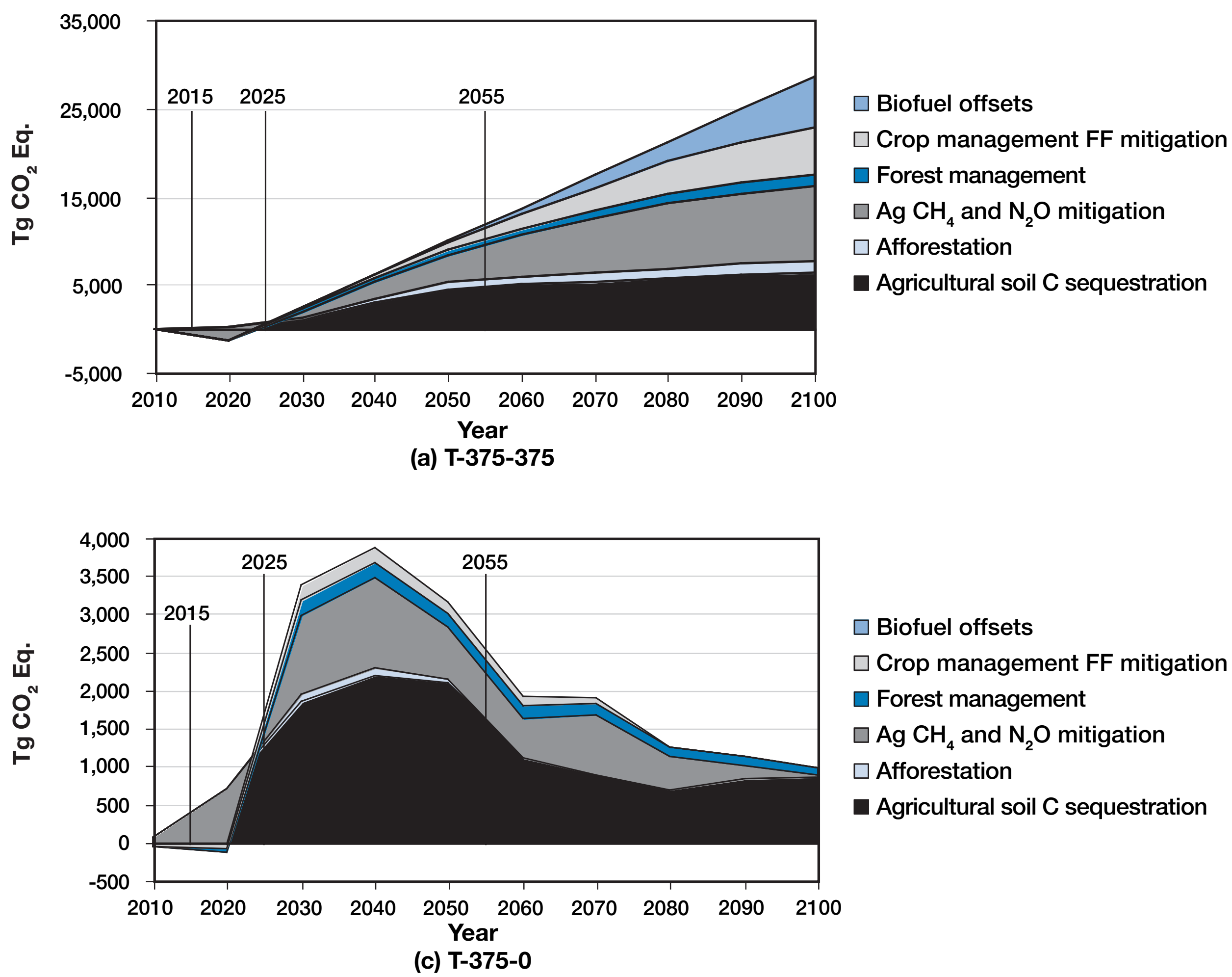
then either maintained, increased, or dropped after that period. Figure 8-3 (reproduced from Figure 5-2) shows the results over time as the fixed mitigation quantities vary.

The first unintended consequence is that the absence of any fixed level for the first decade (2010 to 2020) means that GHG emissions could exceed baseline levels, as producers substitute current (unconstrained) emissions for future (constrained) emissions. This is a form of temporal leakage and is reflected in the initial negative values in Figure 8-3 and occurs under all variations of the scenario.

This situation ultimately reverses when the 2025 mitigation quantity is met. However, another negative consequence occurs when the initial 2025 level is dropped thereafter (the second scenario in Figure 8-3), which leads to a large reversal of the carbon sequestered in the previous decades.

These negative consequences might be avoided if a cumulative mitigation quantity from a base year (e.g., 2010) onward is put in place instead of an annual quantity for the future time period and if the quantity is not dropped in the future.

Figure 8 3: Responses to Set Mitigation Quantities: Cumulative Mitigation to 2100
Quantities are Tg CO_2 Eq. cumulative net emissions reduction below baseline.
Note: Scale varies for each graph, from 4,000 to 35,000 Tg CO_2.



Under scenarios of rising GHG payments, forest and agriculture mitigation action may be delayed.

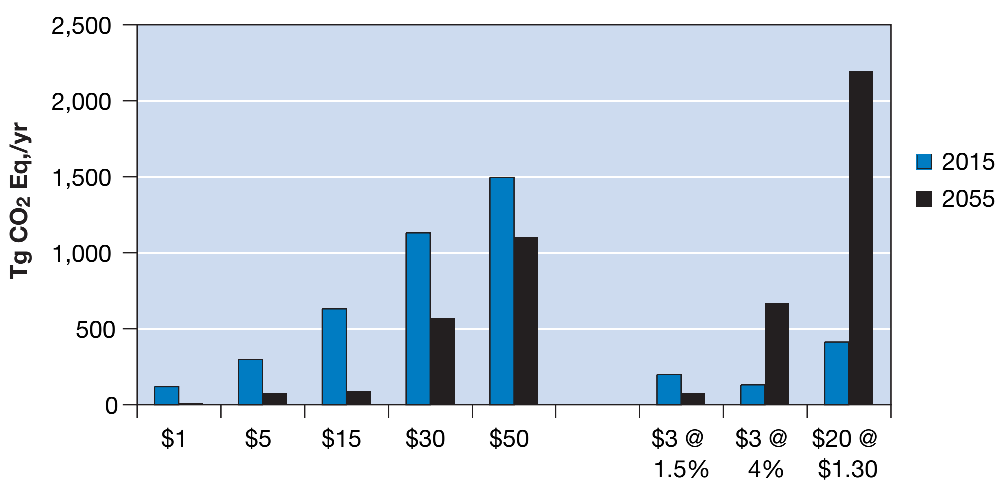
Scenarios simulating a rising GHG price show an increasing rate of GHG mitigation over the first few decades. However, the constant price scenarios show a declining rate of GHG mitigation over the same time period. Three rising GHG price scenarios are evaluated: \$3/t CO_2 Eq. rising at 1.5 percent and 4 percent/yr, respectively, and \$20/t CO_2 Eq. rising at \$1.30/yr. The analyses in Chapter 4 found that, compared to constant-price scenarios, rising prices can lead to delayed action (see Figure 8-4, reproduced from Figure 4-14 from Chapter 4).

The left side of Figure 8-4 shows the constant price scenarios at different levels, and the right side of the figure shows three rising-price scenarios. Rising prices generally cause delayed mitigation. The effect is most pronounced for the two scenarios with the higher rates of future price change. The primary reason for the delay is the "one-shot" nature of carbon sequestration activities. Under rising prices, if mitigation activities occur too early, more carbon will be sequestered at low prices in the near term and less carbon at high prices in the future. The economically optimal response, which the FASOMGHG model generates by assuming that landowners correctly know that prices will rise at the given rate, is to delay sequestration actions to take advantage of higher future prices.

GHG incentives reduce net emissions from the forest and agriculture sectors below baseline levels. If the incentives are strong enough, the joint sectors could move from a net emissions source to a sink.

The FASOMGHG baseline GHG projection for the combined forest and agriculture sectors shows a cumulative net *source* of emissions over time.[1] The mitigation scenarios (see Figure 8-5), however, generate responses that either reduce the size of the joint sector emissions source (at low GHG prices) or even produce a net GHG sink (at high GHG prices).

Figure 8 4: Constant Price Scenarios vs. Rising Price Scenarios and GHG Mitigation
Quantities are Tg CO_2 Eq. per year net emissions reduction below baseline for 2015 and 2055.



[1] EPA's U.S. GHG inventory shows these combined sectors to be a net sink currently; however, the EPA inventory includes carbon sequestration on public forest lands (an additional carbon sink), and FASOMGHG does not, thereby tipping the sectors' baseline GHG balance to a net source in the model.

Leakage potential from limiting included mitigation activities may be largely confined to the forest sector.

Model results in this report and in related research show that leakage potential within the forest sector can be moderate to high, depending on the activity and region (see Chapter 6). If all GHG mitigation activities in forestry and agriculture are included in a comprehensive approach scenario, leakage is negligible. Market effects elsewhere in the United States are captured in the mitigation totals computed by FASOMGHG.

However, if some forest activities and regions are singled out for mitigation, some of the benefits could be offset by emissions from other activities and regions (see Table 8-3). The primary driver of this leakage is the interaction between how much land is devoted to forests, called the extensive margin of forestry, and the intensity with which forests are managed, called the intensive margin. If only afforestation is included as a mitigation activity, but not the management of existing forests, the latter could suffer at the expense of the former, leading to carbon losses from the decline

Figure 8 5: Cumulative Net Emissions/Sinks for Forestry and Agriculture: Comparison of Baseline and Comprehensive Mitigation Scenarios at Constant Prices over Time

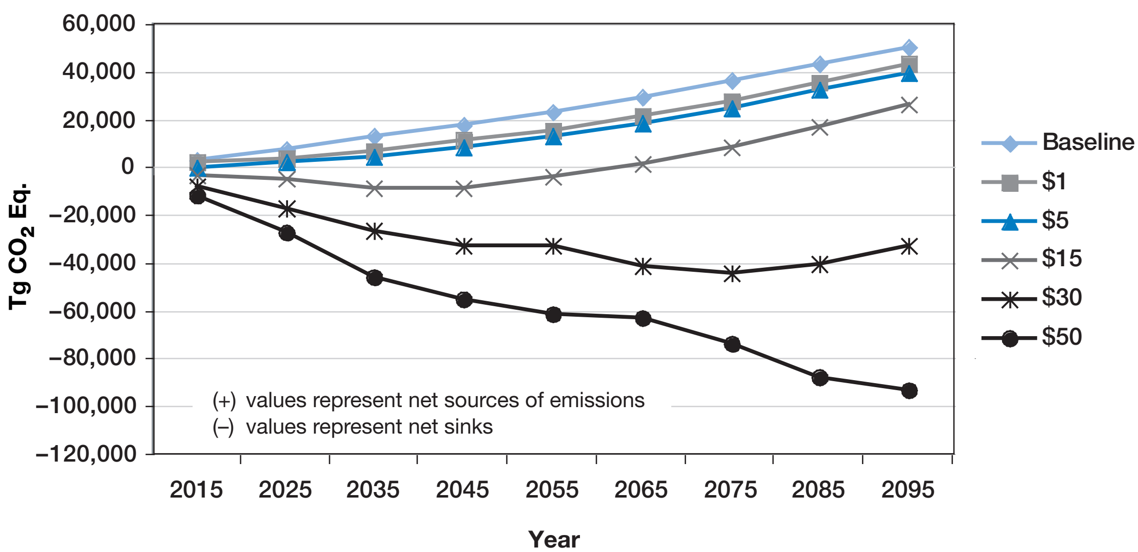


Table 8-3: Leakage Estimates by Mitigation Activity at a GHG Price of $15/t CO_2 Eq.
All quantities are on an annualized basis for the time period 2010–2100.

Selected Mitigation Activities	National Average Leakage Rate (%)
Afforestation only	24.0
Afforestation + forest management	–2.8
Biofuels	0.2
Agricultural management	–0.1
Agricultural soil carbon	5.7

Note: Negative sign indicates beneficial leakage (i.e., the selected activity increases mitigation in the nonselected activities).

in management. However, if both afforestation and forest management are given incentives, the results suggest that this leakage incentive essentially disappears (see Table 8-3).

The agricultural activities evaluated in this report do not appear to be as prone to leakage as forestry activities. Leakage estimates from the agricultural options were found to be less than 6 percent of the direct mitigation benefits. The reason for more limited leakage effects in agriculture is that the changes in agricultural practices do not have as profound an impact on agricultural commodity markets as the forest activities do on timber markets.

Raising GHG mitigation levels in forestry and agriculture can cause environmental co-effects, both good and bad.

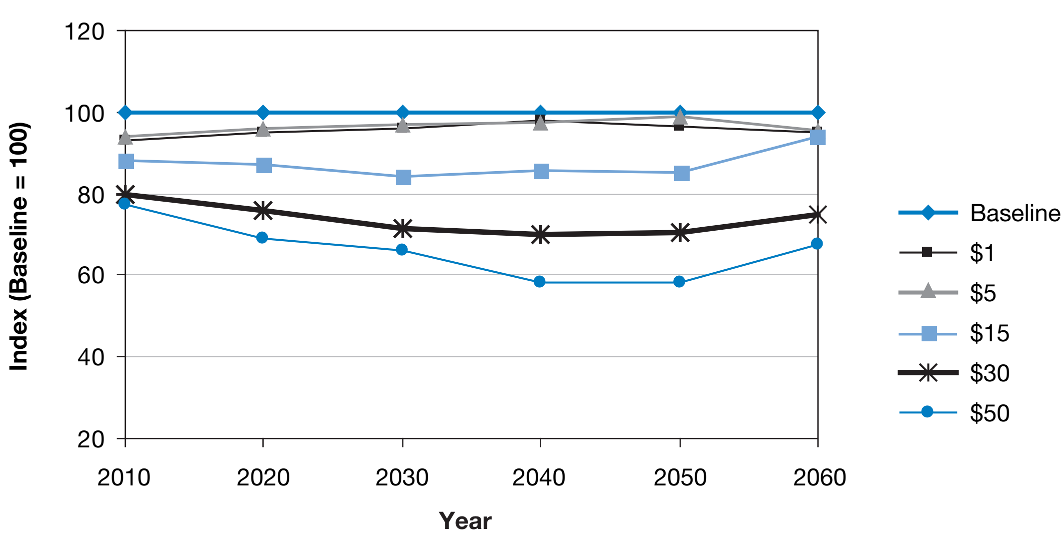
Large changes in land use and production can also have a substantial impact on non-GHG environmental outcomes in forestry and agriculture, primarily because of the role of agricultural soil carbon sequestration in the mitigation portfolio at a fairly low GHG price scenario (e.g., $5/tonne CO_2 Eq.). Even such a low GHG price can induce changes in tillage practices across many cropland acres. These practice changes also reduce erosion and nutrient runoff to waterways as a co-benefit but can lead to a modest increase in pesticide use as a co-cost (Figure 8-6). Other potential environmental effects, such as biodiversity issues, are not modeled in this report but are addressed in Chapter 7.

Taking these environmental co-effects into consideration could affect the relative attractiveness of competing mitigation options. In general, a modest GHG mitigation action will probably have negligible effects on non-GHG outcomes within the sectors. However, the more aggressive the mitigation action, the more likely that co-effects may factor into the net benefits of GHG mitigation.

Payment method will determine efficiency of mitigation activities.

Paying on a per-tonne CO_2 Eq. basis is more efficient than paying on a per-acre basis to generate additional GHG mitigation. Compared to the scenario paying for afforestation only (at $15/t CO_2 Eq.), paying for afforestation on a uniform $100 per-acre basis generates only 30 percent as much additional carbon but requires 60 percent as much in payments. Per-acre payments do not directly vary with the biophysical potential of the site. The inefficiency could be remedied somewhat by adjusting per-acre payments based on land productivity.

Figure 8 6: Nitrogen Runoff Index over Time by (Constant) GHG Price Scenario



If outreach is needed to deliver GHG mitigation, these efforts might focus in regions with the largest mitigation potential.

As shown in Figure 8-7 (reproduced from Figure 4-11), the regional distribution of mitigation opportunities is skewed toward the eastern United States. Federal and other public lands are not included in this analysis, thereby ignoring mitigation potential on those lands. However, public lands management, if included, would clearly elevate the role of the western United States in a national strategy. On the remaining private lands, however, the regional distribution does vary some with the level of mitigation sought. At low levels of mitigation and prices, the two South regions (South-Central and Southeast), via forest management, and two Midwest regions (Corn Belt and Lake States), via agricultural soil carbon sequestration, are the focal regions and activities. As prices rise and mitigation levels expand, farmers in the South and Midwest may participate by planting trees on agricultural land. If GHG incentives are strong enough to induce biofuel production, landowner participation could expand beyond the Midwest and South to include the Northeast region.

Figure 8 7: Total Forest and Agriculture GHG Mitigation by Region
Quantities are Tg CO_2 Eq. per year net emissions reduction below baseline, annualized over the time period 2010 2110.