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# Agricultural & Forestlands: U.S. Carbon Policy Strategies


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Pew Center on Global Climate Change

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## U.S. Carbon Policy Strategies

**Prepared for the Pew Center on Global Climate Change**


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*September 2006*

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## **Foreword** *Eileen Claussen, President, Pew Center on Global Climate Change*

The vast lands of the United States offer significant opportunities to contribute to solving the problem of climate change. At costs well under $100 per ton of carbon, it may be possible to offset nearly 20 percent of current U.S. carbon dioxide emissions through reforesting marginal agricultural lands and restoring carbon to agricultural soils through practices such as no-till and improved crop rotations. Emissions can also be reduced by substituting biomass energy for fossil fuels and by reducing the intensity of wildfires through thinning and removing excess debris. However, for U.S. forest and agricultural lands to play a significant role in curbing climate change, a substantial national policy commitment will be necessary.

This report reviews the available resources and considers the range of policy approaches that would include U.S. forest and agricultural lands in a domestic policy. Kenneth Richards, Neil Sampson, and Sandra Brown identify four basic policy approaches and find that different approaches are suited to different lands. The approaches also vary with regard to who bears the implementation costs—the public at large or specific groups within it—and in expected magnitude of results. For these reasons, a successful forest and agricultural lands program will require some mix of the four approaches:

- Changing practices on public lands,
- Land use regulations on privately owned forestlands,
- Practice-based incentives for forest and agricultural lands, and
- Results-based incentives for forest and agricultural lands.

They find that:

- U.S. Department of Agriculture programs that encourage best practices are familiar to and popular with farmers and forestland owners. As a result, we should evaluate those programs and expand the most effective ones.
- We need to do a better job of having landowners, rather than the government, be the ones to determine what information they need.
- Regulation of private land is primarily an opportunity for state and local government rather than the federal government.
- Results-based incentives, i.e., offering payments per ton of sequestered carbon, can encourage more cost-effective and innovative approaches, but will require development and agreement on consistent and reliable accounting methods.

So how should this inform policy-making? First, we should include land-based sequestration in federal legislation, including the Farm Bill and proposals that address climate change. Second, we should promote opportunities for farmers to move from traditional crop support to environmental and energy-security goals. Third, we should be managing large tracts of forestland sustainably, thus providing both for sequestration and habitat.

This report is being released with a companion report, *The Role of Agriculture in Greenhouse Gas Mitigation*. While this paper focuses on policy options, the companion report reviews the economic and technological opportunities available to farmers—including using cropland to produce biofuels—and estimates the greenhouse gas reductions that could be achieved. Taken together, these reports provide a comprehensive review of the role of U.S. forest and agricultural lands in a domestic climate change program. The Pew Center and the authors would like to express appreciation to Craig Cox, Debbie Reed and Brent Sohngen for reviewing and providing suggestions on an early draft of this report.

## Executive Summary

Agricultural and forestlands can play a key role as part of a comprehensive strategy to slow the accumulation of greenhouse gas emissions in the atmosphere. Much of the public discussion about using these lands as part of an overall strategy to address climate change results from the beliefs that forest and agriculture land-use and management options will be relatively low cost, and that biomass can play an important role in reducing the use of fossil fuels. In the near term, these lands can be managed to increase the quantity of carbon stored in soils and plant matter, thereby reducing net emissions of the primary greenhouse gas, carbon dioxide. In many cases the changes in land-use management that increase carbon storage provide multiple benefits—such as erosion control, water quality protection, and improved wildlife habitat—that by themselves justify the new practices. Over longer time horizons, agricultural and forestlands can produce biomass-based substitutes for fossil fuels, thereby further reducing emissions.

This report examines the wide array of ways in which forest and agricultural lands can be managed to store or "sequester" carbon and reduce net emissions (hereafter we use the term "sequestration" for the process by which carbon is removed from the atmosphere by plants and stored in soils and trees). It discusses a range of policies and programs that would promote this objective and evaluates them in terms of their cost, environmental effectiveness, and other considerations. The results of this analysis suggest that, by carefully designing and implementing a large-scale forest and agricultural carbon sequestration strategy, the United States could substantially reduce its net carbon dioxide emissions. A successful strategy is likely to encompass a variety of initiatives at the national, state, and local levels, and to involve both government and private parties. No single approach will suffice.

Much of the infrastructure needed to increase carbon sequestration on agricultural and forestlands is already in place. To capitalize on sequestration opportunities, the federal government will need to address the full range of practices available for conserving existing carbon stocks and for promoting additional carbon uptake and storage on forest, crop, and grazing lands. A successful national strategy will also need to be responsive to the different types of land and landowners involved, to draw on the existing network of organizations, and include a variety of policy tools. On public lands, for example, government

agencies, personnel, and resources can be directly deployed to pursue sequestration goals. On private land, the federal government has typically had to rely on incentives to influence land management and use. Regulatory approaches have been used on private forestlands, but have been carried out by states because of historically stiff political resistance to federal intervention in state powers to regulate land use.

There are three basic ways in which forest and agricultural lands can contribute to greenhouse gas reduction efforts: conversion of non-forestlands to forests, preserving and increasing carbon in existing forests and agricultural soils, and growing biomass to be used for energy. The costs and potential contributions associated with these three strategies vary widely. Conversion of an estimated 115 million acres of marginal agricultural lands in the United States to forests could sequester an additional 270 million metric tons (MMT) of carbon per year over a period of 100 years, at marginal costs in the range of $50 per metric ton of carbon ($45 per short ton[1]). 270 MMT of carbon stored in forests would offset nearly 20 percent of current emissions of carbon dioxide from U.S. combustion of fossil fuels. However, 115 million acres equals nearly 1/3 of currently cultivated cropland and, even though some of this conversion might be economic, conversion on this scale would require a significant federal effort and likely meet with resistance from agricultural business and rural communities. Initial national studies also suggest that up to 70 MMT could be sequestered annually on agricultural lands through modification of agricultural practices if moderate incentives were available (up to $50 per metric ton of carbon; $12.50 per metric ton $CO_2$). In addition, with yield improvements and cost reductions in the technologies, it may be possible to offset as much as 9 to 24 percent of current emissions through use of biofuels produced at costs competitive with fossil fuels.

In a perfect world the most cost-effective practices—both source control and carbon sequestration—would be adopted first, with more costly approaches implemented successively as net emission reduction goals require. In practice, many approaches may be used simultaneously for a combination of practical, programmatic, and political reasons.

Carbon sequestration programs will not be implemented in a policy vacuum. New program design will need to take existing programs, regulations, and resources into consideration, including the large and sophisticated infrastructure that supplies the nation's many forest and agriculture landowners with educational, technical, and financial support. A key asset that the government has at its disposal is the resourcefulness of many of these landowners. Given practical and political considerations, incentive-based approaches combined with technical assistance are the most effective and feasible policy tools the federal government will have to begin implementing a domestic carbon sequestration strategy. Moreover, the structure needed to deliver incentives for sequestration is already in place in the form of numerous programs contained in the 2002 Farm Bill, including the Conservation Security Program, the Conservation Reserve Program, the Environmental Quality Incentives Program, and the Wildlife Habitat Incentives Program. The government has a great deal of experience with these programs, and, although each was designed to promote specific activities or land management practices, many of the targeted practices also sequester carbon. The practice-based approaches incorporated in these programs have received broad political support. Indeed, it may well be possible to achieve substantial gains in carbon conservation and sequestration simply by relying on existing institutions and programs. In many cases, greater gains could be achieved by increasing budgets and expanding programs. Thus, the federal government should provide substantial and sustained funding for Farm Bill programs that have been successful in promoting carbon sequestration.

An alternative to providing incentives for specific activities or management practices is to employ results-based approaches that provide rewards to landowners in proportion to the actual amount of additional carbon sequestration they achieve. This approach is foreshadowed in the domestic 1605(b) voluntary reporting program. It is also reflected in the Clean Development Mechanism of the Kyoto Protocol at the international level. The advantage of a results-based approach is that it encourages private landowners and project developers to develop innovative land-management practices that are adapted to local conditions. Rather than prescribing the sequestration practices for which the government will pay, the results-based approach frees the landowner to take whatever steps are appropriate to increase carbon stocks, and the reward is directly proportional to the accomplishment.

Incentives or rewards in a results-based program could take several forms. Two leading candidates are subsidy payments and carbon credits. A subsidy payment would take the form of an announced price—in dollars per ton—that the government would pay for carbon sequestration. This approach could be implemented by modifying existing government incentive-based programs. Alternatively, carbon credits could be established in conjunction with a “cap-and-trade” program. Large point sources such as power plants could be allowed to meet their caps, at least partially, by purchasing emission credits awarded for increasing sequestration on forest and agricultural lands. This approach would allow private landowners to receive income for sequestering carbon and would assist entities subject to emission caps to meet their targets at lower costs.

However, results-based approaches are less familiar to the agricultural and forest communities than existing programs that provide incentives for specific practices. Moreover, if credits are allocated to individual landowners under a results-based approach, the government will have to insure that there are adequate methods to provide consistent, reliable, quantified estimates of the greenhouse gas impacts of changes in land management and use. If the government can gain broad acceptance for a results-based approach, and develop the estimation protocols needed to gauge the appropriate rewards, it may be possible to unleash substantial creativity among the broad range of landowners in the United States in achieving increased carbon sequestration.

The government can employ all of the approaches described in this report—providing educational programs through its extension services, enhancing sequestration on government land, urging states to adopt regulations that encourage carbon sequestration, providing incentives for sequestration-promoting practices, and developing results-based programs—to achieve the greatest effect.

## I. Introduction

*Agricultural and forestlands play a role in climate change mitigation efforts because carbon accumulated in soils and trees represents carbon dioxide that has been removed from the atmosphere.* The purpose of this report is to examine what programs and policies the United States can use to address these terrestrial carbon stocks—including sequestering new carbon and conserving existing carbon stocks—and how credible claims can be made regarding changes in carbon stocks. To examine these two issues it is necessary to explore the types of agricultural and forestry activities that will increase carbon storage or conserve existing carbon stocks, the tools available to motivate landowners to change their management practices, and how carbon sequestration accomplishments might be measured.

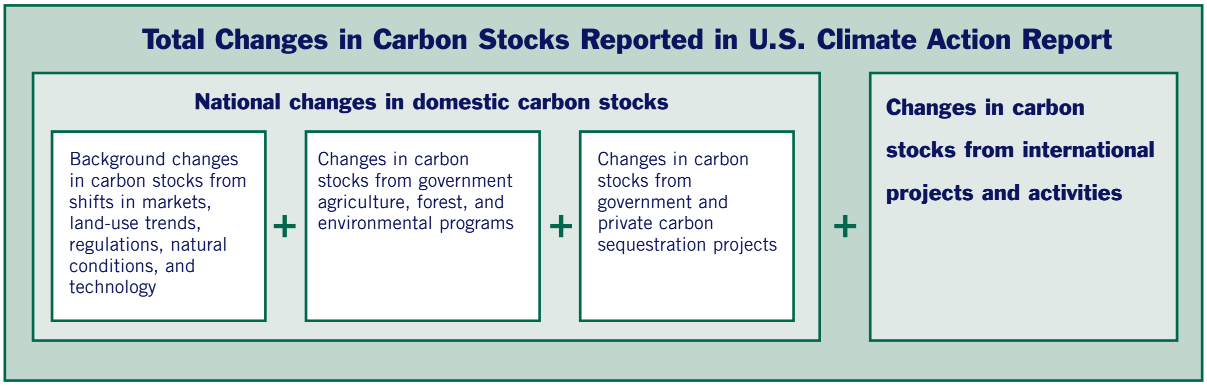
The physical resources available for carbon sequestration in the United States are significant. A large forest and farmland base provides tremendous opportunities to increase and conserve terrestrial carbon stocks. Perhaps most significantly, the amount of land in crops and grass is declining, and much of this acreage is being allowed to undergo a natural process of regeneration to forests. Active management of this transition could sequester additional carbon.

One of the challenges the United States will face, however, is that there are millions of farm and forestland owners. A sequestration program open to all of these landowners may present significant administrative hurdles. As policy-makers consider alternative approaches for implementing a sequestration program, they will have to accommodate a large variety of practices on several different land types, as well as potentially large numbers of participants.

The net change in national terrestrial carbon stocks will be the result of several factors (Figure 1). First, there are background changes that affect patterns of land use and carbon stocks on agriculture, forest, and other lands. Background changes include market-related shifts, technology changes, natural changes, and ongoing general land-use regulations. These background effects can lead to significant changes in carbon stocks over time. Second, there are many governmental programs in the agricultural and forestry sectors under which carbon sequestration is one among many goals. Third, there are projects,

***Figure 1***

Components of **Reported National Carbon Sequestration Gains**




sponsored by both government and private organizations, whose primary purpose is to increase carbon stocks. These three forces combine to determine domestic gains or losses in carbon sequestration at the national level. In addition, the United States may choose to encourage or sponsor international projects and activities, the effects of which the U.S. government can also include in its periodic updates to the U.S. Climate Action Report (U.S. Department of State, May 2002).

This report is structured as follows: Chapter II reviews the context within which any carbon sequestration program would be implemented. It considers the physical, organizational, and cultural resources that can be brought to bear on the effort to enhance carbon stocks. Chapter III provides an overview of the types of activities that could potentially increase carbon sequestration on agricultural and forestlands. It also considers costs and magnitudes of the changes in carbon stocks that could be achieved in the United States and other countries if certain sequestration practices were adopted. Chapter IV examines and evaluates the cost and environmental effectiveness of the policy tools that could be used to influence landowners' management practices, including direct government action, regulations, education programs, and practice- and results-based incentives. Chapter IV focuses on how the government and private landowners might share decision-making and financial obligations under different implementation approaches. The chapter also considers how various policy tools have evolved, in both federal legislation and state forestry programs, and the challenges associated with offering results-based incentives for carbon sequestration to private projects. Chapter V provides a synthesis and offers a coherent approach to carbon sequestration that would promote multiple goals within the context of current political constraints.

## II. The Context for a National Carbon Sequestration Strategy

*As the United States develops a strategy to encourage landowners to adopt practices that increase carbon stocks on the land, it is useful to understand the context within which key parties are acting.* The United States is fortunate to have a well-developed support system for agriculture and forestry that includes federal and state agencies, state research universities, an extensive system of data collection, a large land base, and a resourceful community of agriculture and forestry landowners. While not all landowners are innovators, the recent and rapid adoption of new agricultural practices such as conservation tillage, and of new forestry initiatives such as forest certification,[2] is indicative of a capacity for change that carbon sequestration policies should seek to harness. This section of the report reviews the institutional, physical, and cultural contexts in which a U.S. carbon sequestration strategy would be developed and implemented.

### A. Land-Management Resources

*Land management policies in the United States are implemented through a highly developed and complex array of public agencies and institutions at the federal, state, and local levels.* In addition to federal institutions and 50 state agencies, there are some 3,000 counties as well as several thousand special-purpose local institutions involved with land-use regulation or management programs. Each of these governmental institutions and organizations is potentially relevant to a national strategy to use the U.S. land base to reduce net greenhouse gas (GHG) emissions. One particularly relevant aspect of this multi-level arrangement is that federal agencies tend to use rewards and inducements to encourage private landowners to adopt desirable land-use and management practices, while state agencies rely somewhat more heavily on mandatory or imposed requirements. Where federal regulations are involved (e.g., water quality standards, pesticide regulation), these are often implemented by state agencies and are, in some cases, supplemented by state laws.

The U.S. Department of Agriculture (USDA) oversees most of the federal programs available to assist private landowners in improving land management and conservation. The USDA's programs are administered through a complex institutional framework that includes cooperating federal, state, and local government agencies; non-governmental organizations; and private providers. This institutional network reaches into every corner of the nation and is available (usually free of charge) to every rural landowner or land manager. The USDA's influence throughout this network creates the potential for new federal programs to be incorporated and implemented effectively. That "potential" is not necessarily easy to achieve, since most of the relevant institutions and agencies have faced serious budget and personnel shortfalls in recent years. The USDA's potential could, however, be more fully realized if the national commitment to achieving program goals is adequate.

The USDA programs use incentives to help landowners apply and maintain improved conservation and forestry practices on their land. Historically, the basic mechanisms have been education, technical assistance, and economic incentives. In each program, landowners have been free to participate, or not, as they choose. In 1985, landowners wishing to receive farm income support, price support, and conservation payments from USDA programs were required to plan and install conservation systems on their land. This "conservation compliance" approach was the first time any "stick" had been added to the "carrot" approach.

In this system, it has been common for much of the impetus behind new environmental and economic policies to originate with the federal government. Policies are translated into federal programs, some are assigned to federal agencies for federal implementation, but many others are either handed off to state and local authorities, or assigned to a federal agency that relies on state and local partners for much of the actual implementation. This system allows for relatively quick nationwide action on new initiatives, but it can also lead to significant confusion and frustration as the details get translated differently by different players or encounter local situations where they do not always fit (Healy, 1976).

Traditionally most programs involving land-use regulation have been developed and implemented at the state and local levels. Historically, political opposition has prevented all efforts at comprehensive land-use legislation at the federal level, although some specific policies—such as providing federal support for state-level planning in coastal zones—have been successful. Moreover, the Fifth Amendment of the U.S. Constitution, which bars the federal government from taking private property for public use without just compensation, and the Fourteenth Amendment, which applies the same restriction to state government, limit the degree to which government at any level can regulate land use without actually condemning and paying for the land. State government is also the ultimate source of the "police power" which is the constitutional basis for land-use regulation (Healy, 1976). While there have been numerous legal arguments and rulings over the extent of states' ability to use this power, the general political effect has been to generate significant controversy over land-use regulations virtually everywhere in the United States.

## B. Physical Resources

*The United States has substantial physical resources for increasing carbon sequestration levels.* The country occupies a huge and complex land base of about .26 billion acres (Table 1), with about 1.9 billion acres in the contiguous 48 states and the remainder in Alaska, Hawaii, and the Caribbean.

While the proportion and amount of land within each major land-use category has remained fairly stable over time, non-federal lands have undergone considerable land-use changes in recent decades. Since 1982, data produced by the National Resources Inventory (NRI) have provided some insight into the amount of land being converted between major uses (Table 2). Table 2 indicates that the total amount of non-federal forestland increased only about 1 percent (four million acres) between 1982 and 1997. The four million acre net change tends to mask the fact that land-use changes affecting forests totaled almost 50 million acres during this 15-year period. Some 20 million acres of cropland

***Table 1***

**Ownership and Land Use** in the United States, by Major Categories, 1997

| | Million Acres | | | | | |
|---|---|---|---|---|---|---|
| **Ownership** | **Cropland** | **Pasture/Range** | **Forest** | **Other** | **Total** | **Percent** |
| **Federal** | — | 152 | 247 | 248 | 647 | 29 |
| **Other public** | 3 | 40 | 70 | 83 | 195 | 9 |
| **Indian** | 2 | 36 | 11 | 6 | 55 | 2 |
| **Private** | 450 | 352 | 420 | 145 | 1,366 | 60 |
| **Total** | **455** | **580** | **747** | **481** | **2,263** | **100** |
| **Percent** | 20 | 26 | 33 | 21 | 100 | — |

Note: The estimates in this table were developed by the USDA Economic Research Service from a variety of sources. These data are collected and published on a 5-year inventory cycle. They form the basis for national estimates of land-use and cover change that can be used to calculate terrestrial carbon stocks at national, regional, or state levels. As these inventories gain both in the time periods they cover and in their statistical rigor, they become more and more valuable for understanding the dynamics of the American land resource.

Source: Vesterby and Krupa, 2001.

and 7 million acres of other uses were converted into forest, while around 22 million acres of forest were converted into non-forest uses. (Note that the five million acre change obtained by summing individual changes does not match the four million acre total change due to rounding differences.) The largest conversion of forest into non-forest uses involved 12 million acres that moved into the miscellaneous category, representing primarily urban development and associated uses such as roads. These land-use changes affect carbon stocks, so having statistically valid periodic surveys from the NRI is an essential base for reporting carbon-stock changes at the national level.

As Table 1 illustrates, 60 percent of the land in the United States is held in private ownership. When Alaska (which is mainly in public or Indian ownership) is removed, the fraction of privately owned land jumps to over 70 percent. As a result, achieving public conservation goals in the United States depends on obtaining the cooperation of private landowners. Many private land holdings are small. For example, in the case of forests, owners of less than 50 acres make up 86.5 percent of all owners while representing around 19.6 percent of the forestland base (Table 3). Similarly, for farm land, 50 percent of all U.S. farms sell less than $10,000 worth of agricultural produce a year, and those farms represent only about 10.7 percent of the land area in farms (Table 4).

***Table 2***

### Land Use Transition Matrix 1982-1997 (in millions of acres)

| Land Use | Cropland | Grass | Forest | Misc. | Other | 1982 levels |
|---|---|---|---|---|---|---|
| **Cropland** | **509** | 6 | 20 | 16 | 1 | 552 |
| **Grass** | 11 | **396** | 3 | 5 | 3 | 416 |
| **Forest** | 6 | 2 | **380** | 12 | 2 | 403 |
| **Miscellaneous** | 3 | 1 | 3 | **116** | — | 123 |
| **Other** | 1 | 2 | 1 | — | **396** | 399 |
| **1997 levels** | 529 | 406 | 407 | 149 | 402 | **1,893** |

Note: Numbers in bold indicate acres that did not change use between 1982 and 1997. Non-bold numbers represent land that changed use between 1982 and 1997. A non-bold number indicates the acreage that moved out of the land use category shown on the left and into the land use shown at the top of the column. For example, the non-bold "6" in the top row, second column, indicates that between 1982 and 1997, six million acres were moved out of cropland and converted to grassland. The "11" in the second row, first column indicates that 11 million acres moved out of grassland and converted to cropland. These data reflect changes on non-federal land outside of Alaska, which is not included in the NRI. The "Other" category in this table includes primarily federal lands that are not inventoried as part of the NRI.

Source: Vesterby and Krupa, 2001.

At the other end of the scale, Tables 3 and 4 illustrate another basic fact: much of America's private land is held by a relatively few large landowners, often corporations or organizations. Approximately 75 percent of all farmland is concentrated in 30 percent of the farms. Even more striking, 45 percent of all forestland is held by less than one percent of the forestland owners.

*Table 3*

## Private forestland Owners

by Size of Forest Holdings, 1994

| Acreage Category | 1994 Owners | Percent of Total | 1994 Acres | Percent of Total |
|---|---|---|---|---|
| 1-9 | 5,795,000 | 58.53 | 16,600,000 | 4.22 |
| 10-49 | 2,762,000 | 27.90 | 60,400,000 | 15.36 |
| 50-99 | 717,000 | 7.24 | 47,200,000 | 12.00 |
| 100-499 | 559,000 | 5.65 | 91,600,000 | 23.29 |
| 500-999 | 41,000 | 0.41 | 24,500,000 | 6.23 |
| 1,000+ | 27,000 | 0.27 | 153,000,000 | 38.90 |
| **Total** | **9,901,000** | **100.00** | **393,300,000** | **100.00** |

Source: Sampson and DeCoster, 1997, using data from Birch 1996.

The Natural Resources Conservation Service (NRCS) has estimated that ownership of farm and ranch land in the United States involves around 4.7 million people (USDA-NRCS, 1996). Adding farm owners to the almost ten million forest owners, even with some overlap in the estimates, it is safe to assume that rural landowners number in the range of 14-15 million.[3]

Two points emerge from this examination of ownership patterns. First, ownership of agricultural and forestlands ranges from very small to very large landholders. Programs that may be appropriate for large landholders, who are likely to be highly-capitalized, sophisticated, full-time managers of their land, may not be appropriate for small landholders for whom farming and forestry is a secondary activity or even a hobby. Second, programs designed to promote carbon sequestration on both farm and forestlands may have to deal with very large numbers of participants. As a practical matter it will be important to keep these programs simple to administer.

*Table 4*

## Percent of U.S. Farms & Land in Farms

by Economic Sales Class, 1997

| Economic sales class | Percent of total Farms | Percent of total Land | Average size farm (acres) |
|---|---|---|---|
| $1,000-$2,499 | 23.6 | 3.2 | 64 |
| $2,500-$4,999 | 14.2 | 3.2 | 106 |
| $5,000-$9,999 | 12.3 | 4.3 | 164 |
| $10,000-$19,999 | 11.0 | 6.2 | 265 |
| $20,000-$39,999 | 9.9 | 9.6 | 456 |
| $40,000-$99,999 | 12.1 | 19.0 | 739 |
| $100,000-$249,999 | 10.0 | 24.0 | 1,129 |
| $250,000-$499,999 | 4.1 | 14.0 | 1,607 |
| Over $500,000 | 2.8 | 16.5 | 2,773 |
| **Total** | **100.0** | **100.0** | **471** |

Source: USDA-NASS, 1998.

## C. Human Resources

*One of the greatest challenges facing the institutions that work with landowners in the United States is the significant cultural, educational, and technological change that has marked the 20th Century.* From the time that Abraham Lincoln signed the 1862 law creating the Land Grant University System through the growth of the national forestry, research, extension, and soil conservation programs in the period 1880–1940, landowners were seen to be largely rural, less educated, and less connected to information sources (Sampson and DeCoster, 1997). Thus, public programs were designed to develop new and more effective means of land-use and resource management (i.e., research), to educate new generations of farmers and foresters in their use (teaching), and to employ a variety of communications and outreach strategies (extension services) to help existing landowners learn new methods.

The success of that approach—combined research, teaching, and extension services—is well documented, and it has been copied to some extent in many other countries. But major changes marked the second half of the 20th Century, beginning at the end of World War II. Expanded educational opportunities and the explosive growth of communications affected rural residents and landowners at the same pace as the society as a whole. Instead of relying almost solely on their local extension agent for new ideas about farming, forestry, or soil conservation, landowners could increasingly turn directly to a wide variety of information sources such as commercial vendors and university or agency specialists. Today, access to the Internet and its enormous array of information is as common in rural areas as elsewhere, and the percentage of farms that use computers as management tools is rising rapidly. For example, the percent of U.S. farms with internet access more than doubled between 1997 and 1999, to a total of 29 percent (USDA-NASS, 1999). The transition from serving an audience of under-educated and isolated people to effectively reaching an audience that is both educated and sophisticated in the use of modern communications technologies is still underway in many federal and state agencies. Sampson and DeCoster (1997) argue that major program revamping or, in many cases, development of totally different types of marketing and communications strategies will be required. The key change they suggest would be to replace the "outreach" model (which is based on the idea of informed suppliers "reaching out" to an uninformed audience) with an "inreach" model—where information consumers decide what information and type of assistance they need and are encouraged to request it from the suppliers.

A major question facing policy-makers considering a coherent climate change strategy is how to make carbon sequestration programs relevant in light of the capabilities and limitations of today's landowners. Carbon sequestration, as a new environmental service being promoted by government, is not as yet a familiar subject. How will the basic concepts be communicated, and how will new policies be designed so that landowners can readily find out whether or not the practices being proposed are well suited to their resource situation? This is a significant communications challenge that will need to be addressed in light of today's communications technologies. In addition to an effective communications strategy, new policies will also need to provide economic incentives sufficient to encourage landowner entry into activities that may require new investment or create different risks than they have previously experienced. Further discussion of economic incentives and risks are available in the companion Pew Center report, *Agriculture's Role in Greenhouse Gas Mitigation*, Paustian et al., 2006.

One proposed strategy to increase awareness of carbon sequestration opportunities would be to synchronize public efforts with private, market-driven efforts, thus achieving complementarity rather than competition (Sampson and DeCoster, 1997). If landowners are being informed about carbon sequestration by both public agencies and private market forces (such as buyers, advertisers, etc.), they will have increased opportunities to become comfortable with the new concepts. If market incentives become available, for example, through a credit provision under an emissions cap-and-trade program, the amount of public funding needed to produce a targeted level of activity should diminish, improving the political climate for such funding. However, if only market incentives are available, the opportunity to harness the extensive resources of agricultural and forestry outreach institutions and programs is diminished. These observations suggest that U.S. climate policy, rather than relying exclusively on either a market-based approach or on a public program approach, should seek ways to encourage both. Sections D and E of Chapter IV further explore cap-and-trade programs and use of sequestration credits in conjunction with such programs.

## D. Significance of Resource Availability

*As the United States develops a carbon sequestration strategy, it will be operating in a context that presents both constraints and opportunities.* The nation has many assets that can contribute to a successful carbon strategy. The administrative infrastructure is broad and sophisticated, combining federal, state, and local agencies in a network that supplies financial, technical, and political support to landowners. The USDA's capacity to gather and process agricultural and forestry data is unsurpassed. Equally important, agriculture and forestland owners are educated and innovative. They have shown a tremendous capacity to adapt to new needs, programs, and technologies. At the same time they are independent, suggesting that the government will need to approach carbon sequestration as a cooperative venture with landowners, rather than as a mandate imposed on landowners.

The United States is also blessed with large quantities of forest and agricultural lands that are continuously undergoing management changes and transitions among land-use categories. This presents the nation with an opportunity to encourage adoption of practices that provide greater carbon sequestration benefits. The next chapter provides an overview of the many beneficial carbon sequestration activities that could be promoted by a national program.

## III. Carbon Sequestration Practices

*To develop an effective carbon-sequestration strategy it is important to first understand the natural processes, land uses, and land management practices that tend to increase terrestrial carbon stocks.* A national program designed to use forest and agricultural lands to address climate change should have three goals: (1) to increase the uptake or capture and storage of carbon (sequestration), (2) to maintain carbon stocks that already exist (conservation), and (3) to use biomass to substitute for fossil-fuel based products. It should be remembered, however, that all of these positive steps may involve secondary increases in other GHG emissions. For example, trees can be planted on presently non-forested land and nitrogen fertilizer applied to enhance their establishment and growth. Application of the fertilizer can increase emissions of nitrous oxide, a potent greenhouse gas.

The total amount or "stock" of carbon in a pool can be increased if carbon flows *into* the pool are increased and/or if carbon flows *out* of the pool are decreased (see Box 1). For example, conservation tillage increases inputs of plant-based carbon compounds into soils by leaving crop residues on the land, and decreases releases of organic carbon compounds from soils by reducing plowing. Land management can also reduce overall net emissions without increasing terrestrial carbon stocks. For example, using land to grow wood or grasses that can substitute for fossil fuels may require significant changes in land management, but does not necessarily increase the amount of terrestrial carbon stored.

Generally, land-management activities are categorized according to whether they take place on forestland, cropland, or grazing land. Table 5 summarizes key practices for promoting carbon sequestration, conservation of existing carbon stocks, and fossil fuel displacement in each of the major land-use categories. Note that the term *practice*, is being used here for any action taken to change land management, land use, or land cover as a means of increasing carbon sequestration and/or reducing carbon emissions. Practices can be the result of program incentives or unassisted private actions.

*Box 1*

## Measuring Changes in Carbon

To measure organic carbon *flows* within terrestrial ecosystems, it is helpful to separate the ecosystem into different "pools" through which carbon flows and in which it is held for some amount of time. A carbon pool is any system that has the capacity to accumulate or release carbon, such as forest biomass (often subdivided into above-ground and below-ground live biomass, dead wood and litter, and understory vegetation), wood products, soils, oceans, or the atmosphere. For purposes of climate change policy, the goal of a terrestrial sequestration program is to move carbon dioxide out of the atmospheric pool, transform it to carbon, and store it in terrestrial pools. Sequestration is defined as a net increase in the carbon contained in one of these stable terrestrial pools (Watson et al., 2000).

Carbon dioxide moves from the atmosphere into terrestrial ecosystems through photosynthesis by plants. The most obvious increase in terrestrial carbon is in the above-ground growth of plants, where a large fraction can be stored for many decades, particularly in the woody material of trees. In addition, a fraction of the assimilated carbon is eventually transported to the soil. Within the soil, organic compounds provide food and energy for soil organisms. Much of the carbon in these compounds is returned quickly to the atmosphere through decomposition and respiration. Some is transformed into more stable organic forms that may remain in the soil for decades. A small fraction goes into stable organic compounds that may persist in the soil for thousands of years (Schlesinger, 1995; Paul et al., 1997). See Paustian et. al, 2006 for further discussion of these processes.

As carbon flows in and out of any particular pool, the total amount or *stock* of carbon in that pool will change. Thus, one method of estimating the effectiveness of an ecosystem in sequestering carbon is to measure the carbon in each pool at one point in time (typically done on a per unit area basis; e.g., tons per acre), and then re-measure it again at some later date. In an ecosystem, carbon stocks in some pools can increase while stocks decrease in other pools. For the ecosystem as a whole to be sequestering carbon, the sum of all increases must be greater than the sum of the decreases. Where decreases are greater than increases, the ecosystem is a source of emissions. Dividing the net change by the number of years between the two measurements provides an average annual rate of change.

Several of the practices listed in Table 5, including some that produce the highest carbon benefits, involve a land-use change such as the conversion of cropland to trees or grasses. Note that many of the listed activities can be conducted simultaneously on a particular land parcel. For example, fire suppression, modified harvesting practices, and sustainable forestry practices such as thinning, removing deadwood, or planting trees to fill in an under-stocked stand, may all occur on the same parcel of forestland. Consideration of the many practices available and the three land types suggests that there is no "typical" land management practice to promote carbon sequestration, but rather a plethora of approaches.

## A. Land-Use Change

*While there are opportunities to decrease emissions and/or increase carbon sequestration through management changes on producing farm, ranch, and forestlands (as outlined in subsequent sections), the most significant opportunities are associated with land-use change.* These opportunities mainly involve

*Table 5*

## Land Management Practices to Increase Carbon Stocks or Reduce Greenhouse Gas Emissions

| | Activity or Objective | | |
|---|---|---|---|
| **Land type** | **Expansion of stocks** | **Conservation of stocks** | **Offsite sequestration or emissions reduction** |
| **Forest** | • Reforestation<br>• Modified management e.g., fertilization, improved stocking, species mix, extended rotations | • Modified harvesting practices<br>• Preventing deforestation<br>• Change to sustainable forest management<br>• Fire suppression and management | • Wood fuel substitution<br>• Expanded wood products<br>• Extended wood product life<br>• Substitute wood products for concrete/steel<br>• Recycling wood and paper products |
| **Crop** | • Afforestation<br>• Agroforestry<br>• Improved cropping systems<br>• Improved nutrient and water management<br>• Conservation tillage<br>• Crop residue management<br>• Restoration of eroded soils<br>• Conversion to grass or other permanent vegetation | • Soil erosion and fertility management<br>• Water management<br>• Maintenance of perennial crops<br>• Residue management | • Substitute biofuels for fossil fuels<br>• Fertilizer substitution or reduction<br>• Other bioproducts substitution |
| **Grazing** | • Afforestation<br>• Change in species mix, including woody species<br>• Restoration<br>• Fertilization<br>• Irrigation | • Improved grazing systems | • Livestock dietary changes<br>• Herd management |

cropland, and apply particularly to land that is marginal for crop production due to high rates of soil erosion, low fertility, or other limitations. Planting such lands with trees or grass may be both economically and ecologically sound. Federal policies have encouraged these types of land-use changes for decades through programs such as the Conservation Reserve Program (CRP) (see discussion in IV.D).

Converting cultivated cropland to grassland typically increases soil carbon at rates of 0.3 to 1.0 metric tons of carbon per hectare per year for a period of several decades (Lal et al., 1998; Paustian et al., 2006). Conversion of cropland to forest can result in much higher rates of sequestration due to increases in tree carbon in addition to soil carbon increases (Adams et al., 1993; Alig et al., 1997; Stavins, 1999). Sequestration rates for afforestation are generally in the range of two to ten metric tons of carbon per hectare per year (Richards and Stokes, 2004).

Studies in the early 1990s indicated that about 116 million acres of privately owned cropland and pastureland were biologically suited to growing trees and rated as marginal for crop or pasture use under USDA criteria (Parks et al., 1992). At that time, about half of this marginal acreage was cropland and half was pasture, even though it was estimated that over 20 percent would be more profitable in trees as timberland (Parks et al., 1992). In spite of those findings, experience in the Conservation Reserve Program (CRP) demonstrated that farmers are often reluctant to plant trees for a variety of reasons, including the fact that trees limit their flexibility in using the land for other purposes in future years (Esseks et al., 1992). Thus, while it may be technically possible, and even economic, to convert marginal crop- and pastureland to other uses, such changes will not come easily, nor cheaply, and will require significant program efforts on the part of the federal government.

There are afforestation opportunities on other lands as well. Reconstructed surface-mined lands often have degraded soils, and planting adapted vegetation on these lands can begin the process of restoring more normal soil conditions and can sequester significant amounts of carbon (Lal et al., 1998). If nutrient or water deficiencies are not overly limiting, increases in carbon can continue in the vegetation and soil for many decades.

One concern for those who have been analyzing carbon sequestration opportunities is that if cropland is converted to grassland or forestland, the demand for farm products will lead to a conversion of existing pasture or forestland back to cropland. This would diminish the carbon sequestration benefits achieved by the original land-use change. In the United States this “leakage” effect may not present as serious a concern as some have suggested. To regulate crop surpluses, the U.S. government has paid farmers to hold cropland out of production during most of the past 50 years. At present, the amount of cropland set aside in the CRP program (32.7 million acres in 1997) is about 10 percent as large as cultivated cropland (USDA-NRCS, 2000). The 2002 Farm Bill reflects a political decision that this set-aside remains necessary to protect the farm sector economy, and Congress extended the CRP program through 2007 and expanded it to 39 million acres. The implication is that removal of some marginal cropland from cultivation is unlikely to result in conversion of forest or grassland to cropland elsewhere.

Many of today’s rangelands and pastures were originally forested and would be suitable for afforestation. Recent analyses in California, for example, show that about 42 percent of today’s rangelands are capable of supporting forest vegetation and that this rangeland originally resulted from clear-cutting of forests for timber products. The clear-cutting was followed by the introduction of grazing animals during the 1800 to 1900s (Fry and White, 1946; Brown et al., 2004). Brown et al. find that, if afforested with native tree species, about 2.7 million acres of California's rangelands could sequester a total of over 94 million metric tons (MMT) of carbon by the end of a 20-year period at an average cost of less than $20 per metric ton of carbon. Assuming a higher carbon price and/or extending the time period considerably increases the carbon sequestration potential of California's rangelands (e.g., after 20 years, 242 MMT of carbon could be sequestered at costs of less than $50 per metric ton and after 80 years, 1,500 million tons of carbon could be sequestered at a cost of less than $20 per metric ton of carbon).

## B. Forestland Practices

*Forest management provides significant opportunities to increase carbon stocks or reduce emissions of greenhouse gases.* Although afforestation or reforestation[4] of presently non-forested lands may be the most obvious option for expanding carbon stocks, there are also many management practices that could increase carbon stocks in existing forests, often at costs per unit of carbon that are even lower than establishing new forests (Moulton and Richards, 1990). In 1997 there were approximately 747 million acres of forest in the United States (Table 1), a total that has been slowly increasing since the late 1980s (Smith et al., 2004). About 504 million acres are classified as timberland—that is, forestland capable of producing more than 20 cubic feet of wood per acre per year and not legally withdrawn from timber production. It is on this timberland that most forest management is practiced. Seventy-one percent of timberland is privately owned (Table 1), but these private lands accounted for 92 percent of the timber harvested in 2001 (Smith et al., 2004). Forest management techniques that increase carbon sequestration are commonly used in the United States, but their use is not as extensive as might occur if there were policy incentives to encourage them.

Globally, the most visible source of loss of forest carbon stocks is deforestation. Consequently, much of the international focus on preserving carbon stocks has been on preventing practices that result in deforestation. While there is some loss of forestland to urbanization and suburbanization in the United States (see Table 2 and accompanying text on page 6), the relatively low rate of deforestation in the United States suggests other practices may be more important for reducing forest losses. Thinning and removing excess debris can reduce the "fuel ladders" that provide pathways for small, non-lethal ground fires to burn into the forest canopy where they can become intense, stand-destroying crown fires. Thinning and removal of debris are particularly important in the lower-elevation pine forests of the Intermountain West, where a century of fire suppression has created fuel conditions that lead to very large, intense, and destructive wildfires (Sampson and DeCoster, 1998; Covington et al., 2000) (See Box 2). In one study of the Boise National Forest, where these conditions are widespread, it was estimated that an aggressive treatment program featuring the physical removal of excess fuels and the widespread use of prescribed fire would result in a 30 to 50 percent reduction in the average annual wildfire area; a 14 to 35 percent reduction in average annual fire-related carbon emissions; and a 10 to 31 percent reduction in particulate emissions (Neuenschwander and Sampson, 2000). Another study on fire frequency and carbon emissions found that carbon benefits alone may justify the cost of substantial additional fire-management activities (Sohngen and Haynes, 1997).

A major challenge in implementing fuel-reduction treatments is the combination of the cost of collecting and the non-marketability of a great deal of small, low-quality biomass. In areas where there is a market for both sawlogs and pulp chips, the larger, low-quality stems can be chipped and sold. That still leaves many tons of material that has little or no commercial value in the traditional wood products industry.[5] One possibility is to utilize this debris as fuel in energy production facilities. This is technically feasible, and new research continues to improve the economic feasibility (Sampson et al., 2001). If excess fuel, including small, low-quality debris, were used as a fuel in energy production, not only would carbon be conserved by preventing devastating fires, but the use of the biomass for energy production would also reduce fossil fuel emissions (Brown et al., 2004). Obstacles to the use of excess fuel wood however, are significant. Because the material is bulky, heavy, and low in value, it is usually not economic to transport it more than 25 to 50 miles. In most areas, there are no local electricity generating stations or biogas facilities that can use the material. In addition, producing electricity from biomass is currently two to four times more costly than producing it from coal (Paustian et al., 2006).

These challenges are being aggressively addressed by federal agencies, particularly as they relate to federal lands. Based on the National Fire Plan, developed in 2000, the Bush Administration developed the Healthy Forests Initiative in 2002 (USDA, 2005). It is estimated that the threat of catastrophic wildland fire has been reduced on over 15 million acres of federal land since 2000 (USDA, 2005). The challenge of utilizing excess biomass for energy and other products instead of burning it in prescribed fires or wildland fires has been the focus of major interagency policy and program development efforts involving the U.S. Departments of Energy and Interior, as well as the U.S. Forest Service (USDA-FS, 2005).

Other management practices can also have significant effects on increasing carbon stocks in existing forests. Such practices include extending the harvest cycle length and modifying harvest and regeneration practices. Within forests managed for commercial timber production, extending the rotation length from 30 years to 45 or 50 years will add significantly to the standing carbon in the forest and will result in larger logs that can be used for longer-lived wood products such as structural timbers (Row, 1996; Brown et al., 2004). If these longer rotations were encouraged by carbon sequestration policies—including policies that discouraged compensating harvesting elsewhere—market demand could be met by alternative products, increased imports, or harvests from new forest plantations. The net result

***Box 2***

## Carbon Sequestration in the Face of Multiple Objectives: Wildfire and Carbon

As the nation considers the potential role of forests in an overall GHG strategy, one important consideration is the virtual inevitability of large, high-intensity wildfires given the current condition of many forests in the West (Prestemon et al., 2002; Sampson et al., 2000). The GHG emissions from these wildfires ($CO_2$, methane [$CH_4$], and nitrous oxide [$N_2O$]) are a function of the amount of biomass consumed (Leenhouts, 1998). One study in the ponderosa pine forests of Idaho estimated that a high-intensity wildfire consumed an average of 79.5 metric tons of fuel, and emitted approximately 132 metric tons of $CO_2$ per acre. (Neuenschwander and Sampson, 2000). While historical data on wildfires are lacking, evidence suggests that they were much more frequent, less intense, and less destructive, burning over as much as half of the landscape every six to seven years (Everett et al., 2000). These frequent, low-intensity fires were not lethal to the dominant vegetation, consuming something in the range of five to seven tons of fuel per acre (Leenhouts, 1998).

One U.S. Forest Service study estimates that some 18 percent (around 76.5 million acres) of the ecosystems that historically experienced frequent, non-lethal fires have been seriously altered and are now at high risk of losing important ecosystem components or structures in the event of a wildfire (Hardy et al., 2001). This situation is largely the result of settlement, grazing, logging, and fire suppression throughout the 20th Century that affected low-elevation forests most severely (Sampson et al., 2000). In addition to the risks these forests currently face, they may face greater stress in the future due to climate change impacts. Much of that stress will come from insects and disease organisms that may adapt to new conditions more rapidly than trees, opening the way to larger epidemics and increased amounts of dead fuels that are ripe for catastrophic fire (USDA-FS, 2001).

The current situation calls for large-scale fuel treatments to reduce the amount of flammable fuels on the land and restore these forest ecosystems to a more fire-tolerant condition. This work is underway, but will take many years to complete given present rates of progress (USDA-FS, 2005). In the meantime, exceptional wildfire years such as 2002, in which the fire area reached nearly seven million acres, are associated with massive GHG emissions that complicate efforts to achieve emission reductions.

(in terms of carbon) would depend on how market demand was met. In the best case, the result would be larger areas of older forests plus an increase in total forestland due to land conversion of marginal agricultural land to forestland.

How forests are harvested and regenerated also has a significant impact on carbon stocks. Removing all above-ground biomass and subjecting the soil to heavy mechanical disturbance to prepare for tree planting may, in some cases, encourage faster growth of the new crop, but is likely to result in relatively higher soil carbon emissions than other harvesting and regeneration methods. Maintaining woody debris and standing trees for partial shade while minimizing soil disturbance may reduce early tree-growth rates, but can have the benefits of lower carbon emissions and retaining larger carbon stocks on site (Row, 1996). These are trade-offs that forest managers must consider. If carbon sequestration gains are recognized as a public or economic asset, decisions on these practices may be made differently in the future.

Other practices such as thinning, fertilizing, or supplemental planting can also improve forest health or growth rates and result in carbon sequestration. Periodically thinning forests by removing small trees at various stages will allow remaining trees to grow larger, which may in turn store more carbon. On nutrient-poor soils, such as are often associated with coniferous forests, it has been estimated that fertilization could increase forest growth and carbon storage by as much as 0.45 metric tons of carbon per hectare (0.20 short tons per acre) per year, a substantial increase (Tuskan and Walsh, 2001). Where nutrients are applied in proper amounts on soils that are not saturated with water, there should be little or no associated increase in emissions of nitrous oxide ($N_2O$), another potent greenhouse gas (Mosier et al., 2003).[6]

## C. Cropland Practices

*Although the potential for agricultural carbon sequestration is difficult to predict, current estimates suggest that some 70 to 220 million metric tons of carbon per year could be sequestered in soils on current U.S. croplands* (Paustian et al., 2006). In addition, using grasses or woody crops as substitutes for fossil fuels, substituting natural fertilizers for energy-intensive fertilizers, and optimizing fertilizer use can decrease emissions (see Paustian et al., 2006 for further discussion of these opportunities).

*Increasing and Conserving Soil Carbon on Cultivated Croplands*

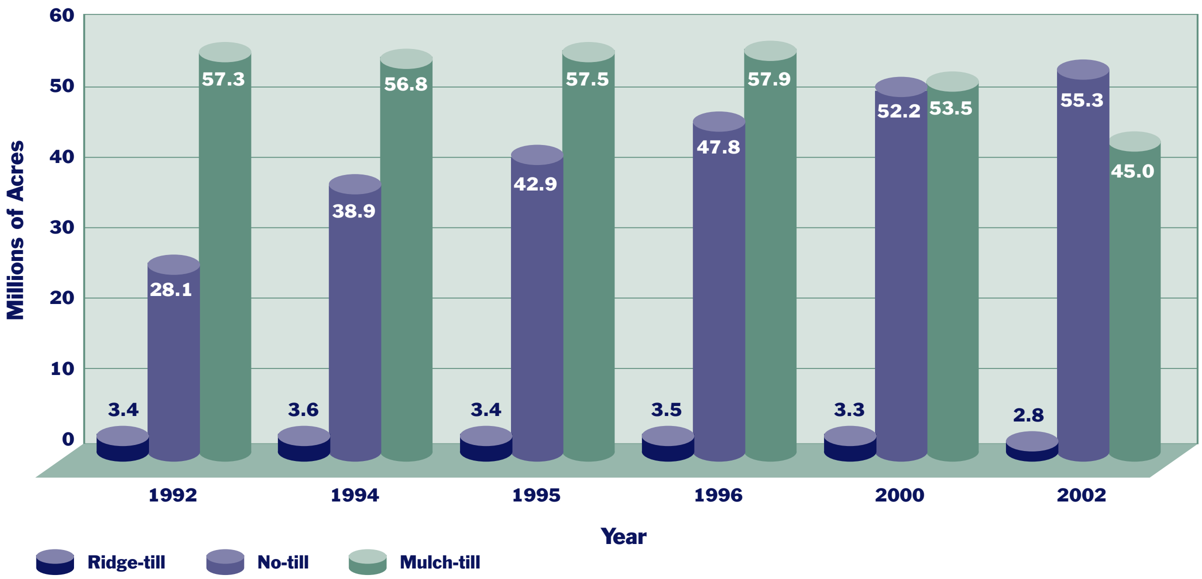
Of the many opportunities to increase and conserve carbon on croplands listed in Table 5, this section focuses on conservation tillage. The companion report Paustian et al., 2006 includes discussions of the full range of practices to increase and conserve cropland soil carbon. Approximately 90 percent of U.S. cropland is cultivated—that is, subject to plowing, weeding, or other practices that disturb the soil (USDA-NRCS, 2000). Cultivation is a major contributor to the loss of soil carbon through increased decomposition and erosion that lead to emissions of $CO_2$. It is estimated that by 1960 soil organic carbon levels in Corn Belt farm soils were about half of 1907 levels due to the effects of cultivation (Lal et al., 1998). However, cultivated soils do not continue to lose carbon forever. After decades to centuries of constant cultivation, the soil carbon content reaches a new equilibrium, where carbon inputs are balanced by outputs. However, this new equilibrium is at a considerably lower level than that of the original land. Changing cultivation practices has the potential to restore some of the "lost" soil carbon.

Increasing carbon stocks on cultivated cropland is primarily a matter of increasing the organic carbon content of the soil (often abbreviated SOC, for soil organic carbon).[7] As noted previously, carbon flows in and out of the soil, and sequestration results if carbon inputs are increased and/or carbon outflows are reduced. The amount of sequestration likely to result from improved practices on agricultural soils is directly related to the degree to which the soil carbon has been depleted by past practices. A depleted agricultural soil can have its carbon stock restored through improved management, although a soil that already contains its optimum carbon stock may have little or no capacity for additional sequestration. In short, the potential for additional carbon sequestration on agricultural soils is related to how depleted the carbon stocks in the soil are at the start of a new carbon sequestering practice (Sampson et al., 2000).

The introduction of conservation tillage methods that significantly reduce soil disturbance has had a major impact on soil carbon in cultivated cropland since the 1970s, when these methods began to be widely used. A recent study of soil carbon in Nebraska concludes that agricultural soils in the state are sequestering around 1.3 million metric tons of carbon (MMTC) per year due to the increased adoption of conservation tillage and other soil conservation practices in the last 10 to 20 years (Brenner et al., 2002). That study also estimated that the current sequestration rate could be maintained and increased to around 2.3 MMTC per year if all cropland in Nebraska were converted to a no-tillage management system.

*Figure 2*

## Trends in Conservation Tillage in the United States, 1992-2002




Note: Three primary types of practices are recognized as conservation tillage. No-till systems leave the soil virtually undisturbed; mulch-till involves tillage, but leaves 30 percent of the crop residue on the soil surface; and ridge-till involves row cultivation that leaves four- to six-inch ridges where the plants are grown.

Source: Conservation Technology Information Center, 2002.

On the national level, the past two decades have seen a significant growth in the adoption of no-till systems. The Conservation Technology Information Center (CTIC) estimates that no-till planting systems were used on more than 55 million acres in the United States during the 2002 crop season, a 97 percent increase over the level ten years earlier (Figure 2). However, to retain the carbon sequestered in the soil, lower-impact tillage practices must be maintained. Although millions of acres of farm land are under conservation tillage practices in any given year, the millions of acres are not the same ones from year to year. The gains in soil carbon from previous conservation tillage practices can be largely lost if the areas are later converted back to conventional tillage.

Conservation tillage systems differ significantly from crop to crop and place to place, and must be carefully adapted to local situations. A switch to conservation tillage may be followed by a transition period during which yields and profits drop while the soil system is re-adjusting to the new management regime. After that transition, however, most farmers find that the cost reductions—due to decreased machinery use and time spent plowing—coupled with the more stable yields of conservation tillage systems result in improved profits (CTIC, 2002). This suggests that the government may have a role in helping farmers make the transition to conservation tillage practices. Further discussion of hurdles associated with practice changes may be found in the Pew Center companion report, Paustian et al., 2006.

For most cultivated crops, conservation tillage systems are available that also effectively reduce soil erosion and water runoff, thus further conserving soil carbon. Cultivated soils are susceptible to soil erosion, both from wind and water. Soil erosion can be a major cause of carbon loss because the erosion processes tend to separate and carry off the lightest and smallest soil particles that have the highest organic carbon content. While some soil erosion and resulting sedimentation may simply move carbon from one site to another, or carry it into deep sediments where it may be protected, it is estimated that 20 percent of the carbon dislocated by erosion will be emitted into the atmosphere (Lal et al., 1998). In addition, eroded sites have a reduced capacity to support plant growth, thus reducing future sequestration potential.

In addition to protecting the soil and promoting the buildup of soil carbon, conservation tillage systems involve less fuel consumption, thereby reducing GHG emissions associated with farming (West and Marland, 2002), providing a good example of how multiple environmental and economic benefits can emerge from practices that promote agricultural carbon sequestration. Some practices serve more to reduce GHG emissions than to conserve or increase carbon stocks on cropland. For example, systems that provide adequate water and fertilizer for optimal crop growth, while avoiding saturated soils or untimely nutrient applications, can reduce emissions of $CH_4$ and $N_2O$, two potent greenhouse gases. Such "optimized" systems are economically beneficial, and provide additional environmental services. See Paustian et al., 2006 for further discussion of management practices that can be used to reduce various agricultural GHG emissions and also provide other environmental benefits.

### *Options on Non-cultivated Croplands*

Non-cultivated cropland is a broad category that includes land uses ranging from perennial forage crops where soils may be cultivated and replanted every few years, to vineyards and orchards that may be uncultivated for decades, to cranberry bogs that are never cultivated. Converting from cultivated to non-cultivated crops may result in significantly increased carbon stocks in the plants (e.g., woody tree crops) and in the soil where previously lost organic carbon may be regained. To promote such gains however, it will be necessary for the government to provide incentives for landowners to switch from cultivated to non-cultivated agricultural practices.

There is increasing interest in the production of crops for energy that could have the dual effect of increasing carbon stocks while producing biomass feedstocks to replace fossil fuels. Energy crops include perennial grasses and fast-growing trees. The biomass from these crops can be used to produce heat, electricity, or transportation fuels. The companion report, *Agriculture's Role in Greenhouse Gas Mitigation* (Paustian et al., 2006) provides an in-depth discussion of the use of biomass for energy.

Switchgrass, a native grass that grows well on marginal croplands in the Midwest, is one crop being tested for use in energy production. In a project in Iowa, switchgrass is being grown and tested as a co-fired fuel in a 700 megawatt (MW) coal-burning power plant operated by Alliant Energy and MidAmerican Energy Corporation. It is estimated that 50,000 acres could produce 200,000 tons of switchgrass annually that could be co-fired with coal, generating a sustained output of 35 MW of biomass-derived electric power and displacing 5 percent of the coal used in the plant each year (www.cvrcd.org/biomass.htm).

In another test of biomass energy, the Salix Consortium of New York is growing hybrid willow in plantations for eventual co-firing in power plants operated by Niagara Mohawk Power Corporation (www.cce.cornell.edu/clinton/forestry/willow.html). The willow crops are harvested every three years, producing an average yield of 7.5 dry tons per acre per year. These plantations will result in increases in soil organic carbon, as well as increased carbon stocks in large roots and stumps, in addition to the atmospheric benefits from substituting biomass for fossil fuel.

Overall, biomass energy appears to be a promising element of a GHG mitigation strategy (Paustian et. al., 2006). Currently costs for ethanol and other biomass-based fuels limit their ability to compete with conventional fuels. However, moderately optimistic scenarios suggest that it may be possible for biomass to offset as much as 9 to 20 percent of current (year 2004) total U.S. GHG emissions annually. Such scenarios assume that R & D succeeds in enhancing crop yields and reducing conversion costs, or that policies place a sufficiently high value on the GHG and other environmental benefits of carbon-neutral fuels. The higher offset value results if biomass replaces coal; the lower number results if natural gas is replaced. Further discussion of the potential of biomass to reduce GHG emissions—including a range of biomass production and use scenarios—is provided in Chapter IV of the companion report, *Agriculture's Role in Greenhouse Gas Mitigation* (Paustian et al., 2006).

## D. Grazing-Land Practices

*According to one analysis, as much as 70 million metric tons of carbon per year could be sequestered on the nation's grazing lands (Follett et al., 2001), although, for a variety of reasons, it may be difficult to achieve this potential.* Many of the grazing lands that could be managed to increase soil carbon are located in areas with harsh climates that limit plant growth, or where historical grazing practices are very difficult to alter. Neither of these conditions is easily overcome by policy changes.

Grazing lands make up about one-quarter of the total land area of the United States (see Table 1, page 5, Pasture/Range category). They are highly complex and encompass very different ecosystems, ranging from tundra—where the main grazers may be reindeer—to highly-managed dairy pastures in the southern United States, to near-desert rangelands in the Southwest and alpine meadows in the Rockies (Follett et al., 2001). In general, rangelands occupy the more arid and semi-arid regions, while pastures are more prevalent in more humid regions (Follett et al., 2001).[8]

The major stable carbon pool on grazing land is the soil, although in many cases, the existence of perennial shrubs or scattered trees can add a woody carbon pool to the total ecosystem carbon stock. The potential for significantly increasing these carbon stocks is limited without major changes in land use and management (Follett et al., 2001). Nevertheless, even small changes in the amount of carbon stored per acre in grazing-land soils can be important because of the large land areas involved.

Overgrazing is the cause of the largest carbon losses in grazing-land systems, as well as the most significant factor in their ecological deterioration (Ojima et al., 1993). Grazing influences the growth and partitioning of above- and below-ground plant matter, changes the temperature and moisture regimes in the soil, and alters the soil's susceptibility to erosion (Follett et al., 2001). Reversing the effects of overgrazing is a complex task in the United States, involving the economic dynamics of livestock-based agriculture and its relationships to both public and private land resources.

Achieving carbon sequestration in grazing-land soils involves increasing plant productivity, which can be achieved through improved water and nutrient management, as well as through grazing practices such as management-intensive grazing. On rangelands, management involves the regulation of herbivore grazing since grazing affects vegetative species distribution, structure, and total productivity and, as a consequence, the susceptibility of soil to erosion (Sampson et al., 2001). Improved management practices that protect rangeland soils from erosion and improve plant productivity can restore lost soil carbon over vast areas.

Management-intensive grazing can make a portion of existing grazing lands available for afforestation activities. This practice increases the density of vegetation, thus providing more forage within the same area and decreasing the amount of land required for a given herd. For example, if a farm has 1,000 acres of grazing land, but adoption of management-intensive grazing reduces the acreage necessary to meet herd needs to 500 acres, the remaining 500 acres could become available for afforestation projects.

Significant management changes on grazing lands will neither be easy to implement, nor do they promise rapid results. In the West, ranchers who have had access to public rangelands for more than a century, and who rely on that access to support their ranching operations, have little incentive to reduce grazing impact. Despite heavy political pressure to increase grazing fees, for example, the political strength of ranching interests has maintained the status quo for many years. On many western lands, moreover, a change in grazing practices today would produce little or no impact on soil carbon levels for years due to the limited moisture and slow plant growth associated with these lands.

## E. Sequestration Costs and Potential Quantities

*Available studies suggest that there are opportunities to significantly increase carbon sequestration levels both in the United States and abroad, in many cases at modest costs.* According to a recent analysis of forest carbon cost studies, in the United States it may be possible to sequester an additional 270 MMT (approximately 300 million short tons) of carbon per year over a period of 100 years at a marginal cost in the range of $50 per metric ton of carbon ($12.50 per metric ton of $CO_2$) by converting marginal agricultural land to forests (Stavins and Richards, 2005).[9] Conversion of marginal agricultural bottomlands to forests is already occurring on many thousands of acres, especially in the Mississippi Valley region. Typically, cost analyses of converting marginal agricultural lands to forests have assumed that the carbon capture rates will average between 1.8 and 7.2 metric tons per of carbon hectare (0.8 and 3.2 short tons per acre) per year (Moulton and Richards, 1990; Adams et al., 1993; Tasman Institute, 1994; Parks and Hardie, 1995; Slangen and van Kooten, 1996). While it may be possible for a national program to sequester more carbon than

300 million short tons per year through the conversion of additional agricultural lands to forests, the costs rise rather rapidly because it would require using prime agricultural land and the opportunity costs of that land are high.[10]

While many opportunities for carbon sequestration exist within the United States, both government and private parties have also demonstrated interest in looking beyond the United States. Developing countries, for example, may offer larger, more cost-effective sequestration opportunities than are available in the United States (Brown et al., 1996; Brown et al., 2000; Kauppi and Sedjo, 2001; Richards and Stokes, 2003; Sohngen and Mendelsohn, 2003; Sedjo et al., 2001). These cost-effective opportunities result from generally higher rates of carbon sequestration per unit area and lower labor and land costs. In addition there is a large opportunity for reducing emissions from forests in many tropical developing countries by slowing deforestation. For such an activity, up to 80 tons of carbon or more can be prevented from entering the atmosphere for every acre protected from deforestation. These low-cost opportunities are reflected in reporting under the U.S. Department of Energy's voluntary reporting program—known as 1605(b)—where the largest quantities of carbon sequestration are for several private projects located in tropical developing countries (see Section IV.E for further discussion of this program).

In addition to land conversion and the prevention of land conversion, there are many practices son both forestland and agricultural land that may result in substantial amounts of carbon sequestration at relatively low costs. While these practices have low carbon sequestration yields per acre relative to the land conversion options, they also present lower capital costs and entail fewer political obstacles and institutional barriers. For example, Moulton and Richards (1990) found that in standing forests, a combination of tree planting and more intensive management for carbon could achieve substantial sequestration at costs of less than $20 per ton of carbon. There have been fewer estimates of the costs of carbon sequestration in agricultural soils. One study, however, indicates that in the United States, economics would limit soil sequestration to approximately 70 MMTC per year, at costs of less than $50 per ton of carbon, although this study did not provide details on the specific practices used to increase soil carbon (McCarl et al., 2001). Lewandrowski et al. (2004) find that soil carbon sequestration can be induced for carbon prices as low as $10 per ton, but also find that very limited quantities of carbon would be sequestered at that price (see Paustian et al., 2006 for further discussion of the economics of soil carbon sequestration). Finally, with energy crop yield improvements and reductions in conversion costs, it may be possible to offset 9 to 24 percent of current emissions levels through use of biofuels produced cost-competitively with fossil-fuels.

### F. Many Practices, Multiple Objectives

*Many different land-use-related activities can contribute to the reduction of net GHG emissions (as summarized in Table 5, page 13), suggesting that if the government is going to promote the use of forest and agricultural lands as part of a larger strategy to address climate change, it may need to employ a variety of approaches.* Many of the practices listed in Table 5 achieve objectives in addition to carbon sequestration, such as increasing soil fertility, protecting watersheds from soil erosion, providing wildlife habitat, and increasing timber yields. Similarly, a strategy to increase carbon sequestration is unlikely to consist of a stand-alone program; more likely it will develop as a complement to an array of land-use-related environmental and economic objectives. (See, for example, Box 2 for a discussion of potential synergies with fire management objectives.)

Differences in ownership present additional challenges to design and implementation of a land-use management program. In each of the three land-type categories shown in Table 1, the United States may want to encourage activities on privately owned lands, on government holdings, and even in foreign lands. Each combination of activity, land type, and land ownership can present a unique challenge to the design of a government program intended to encourage reductions in net emissions. The policy challenges stem largely from the fact that public policy and programs for different land holdings (private, government, and foreign) and for different land uses (particularly forest versus croplands) are developed through completely different political processes involving different public agencies, different Congressional committees, multiple levels of government, and a wide array of interest groups, constituencies, and stakeholders. The next chapter of this report explores the policy tools that the government might use to encourage a wide range of carbon sequestration practices in a variety of contexts.

## IV. Selecting Carbon Sequestration Policies

*Whether the goal is to promote research and education or to induce changes in land-use practices directly, the government must choose among available policy tools.* What policies and programs should federal and state governments use to incorporate U.S. forest and agricultural lands into a broader strategy for addressing climate change? Should they use taxes or subsidies? Regulations or cost sharing? Should they emphasize public ownership or private development? This section begins by describing the basic types of policy approaches. It then discusses each type of approach, starting with reviews of the history of U.S. programs in the agriculture and forestry sectors. This long history provides a base of experience from which lessons can be drawn to inform future programs and policies.

Two of the prime considerations in selecting policies and programs are cost and environmental effectiveness. The studies discussed earlier in this report provide estimates of per ton costs of carbon sequestration. There will also be many less obvious costs associated with implementing a sequestration program. The government must set up the infrastructure (or reinforce the existing infrastructure) to support the program. This may require: personnel for paperwork, budgeting, and related activities; field agents to assure that private parties comply with program requirements; scientists and analysts to carry out research; and extension agents to conduct public education. Sequestration programs may also have monitoring and evaluation costs.

Less obvious still are the public finance costs associated with a carbon sequestration program. Market prices are a valuable tool for conveying information about the costs and benefits of producing various goods and services. In a perfect system—what economists call a "first-best" system, with no price distortions—prices facilitate the market operations that lead to efficient production and consumption levels. When the government raises revenue through taxing goods, labor, capital, property, or other elements of commerce, it distorts the prices and reduces the efficiency of the market system. This leads to inefficient levels of production and consumption and a decrease in the social benefits of the market.

Thus, if the government uses taxes to fund a sequestration program, there will be additional costs associated with the revenue raising activity. The economists' term for these additional costs is "excess burden" or "deadweight loss."

As policy-makers endeavor to minimize the cost of a carbon sequestration program, they must be mindful of several constraints. First and foremost, the design of a sequestration program must assure that the climate change policy goals will be achieved, and that the program is environmentally sound and effective. For example, if the federal government sets a goal to sequester an additional 200 million tons of carbon per year, a program lacking mandates or subsidies—as cost-effective as that might be—is unlikely to achieve the goal. Such a program, coupled with technical assistance or even the threat of eventual mandatory controls, will only encourage landowners to identify actions they can take at little or no cost. While the threshold for voluntary actions depends upon the context, including the extent and form of encouragement brought to bear on private parties, eventually there will come a point where low-cost opportunities are exhausted and financial incentives or sanctions (carrots and sticks) will be needed to induce further action.

Policy tools must also comply with legal restrictions and operate within political constraints. For example, the Fifth Amendment takings clause of the U.S. Constitution restricts the federal government's ability to impose regulations that diminish the value of private property. Some approaches may be theoretically attractive from the standpoint of cost and effectiveness, but may not be viable due to political constraints. For example, although they may be theoretically attractive, it is unlikely that emission limitations will be placed on the agricultural or forestry sectors. This constraint has major implications for the participation of these sectors in a cap-and-trade program. (See discussion under Measurement Issues, Section IV.E.). It will also be necessary to carefully build coalitions to support whatever approaches are adopted to promote carbon sequestration. As politicians, the electorate, and interest groups gain experience with innovative approaches, it may become politically feasible to expand both the type and extent of approaches used. This suggests that even limited applications of new approaches have value insofar as they contribute to a societal learning curve.

As each approach is reviewed in the sections that follow, cost and environmental effectiveness considerations are discussed. One of the conclusions of this review is that no single approach is appropriate for every situation.

## A. The Range of Policy Tools

*Policy-makers should employ policy tools that will achieve the environmental goals of sequestration programs at the least overall cost to society, while being mindful of institutional, legal, and political realities.*

Some policy options will allow the government to retain more control over the sequestration process while others will grant more control to private parties (Richards, 2000). Some options will place the cost of sequestration on the government and taxpayers while others will place the economic burden on private interests. Figure 3 illustrates the range of policy tools that has been used recently to protect the environment and to influence the management decisions of farm and forestland owners. Options are arranged in order of increasing involvement of, and relinquishment of control to, private landowners. In general, policy tools that provide greater flexibility to landowners allow them to find the lowest cost methods to sequester carbon.

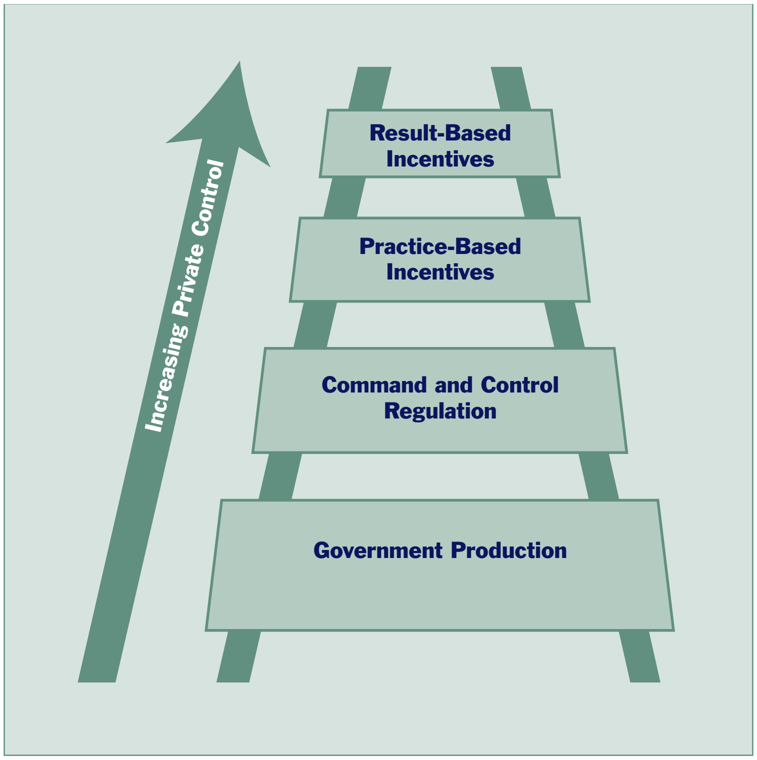
Government production (the lowest rung on the ladder in Figure 3) means that the government uses its own agencies (e.g., U.S. Department of Agriculture and U.S. Department of Energy), resources (e.g., National Forest System or Bureau of Land Management lands), and employees to provide a public good or service, in this case sequestering carbon and providing information for that purpose. For example, the U.S. Forest Service could modify its current land-management practices in National Forests, or the U.S. National Park Service could acquire and preserve new lands, instituting reforestation practices where appropriate. In either case, any additional financial burden for the program would fall directly on the government and taxpayers.

In a command-and-control approach (the second rung on the ladder) the government mandates that private landowners adopt certain practices, and places the financial burden upon them. For example, the government could require that trees be replanted following harvest or, under certain circumstances, even require planting of trees on non-forested land. The costs of such regulations would largely fall on the private sector, minimizing the need for additional tax revenues. In addition, the costs of administration would be low, and monitoring for compliance could be relatively simple. Past experience, however, suggests that this approach may not be an option for federal programs.

Efforts to impose federal regulations on private forest practices ran almost continuously from the 1920s to the 1950s, and although they never succeeded, they were the source of much political debate

*Figure 3*

**The Policy Tool Ladder**




and acrimony (Cubbage, 1995; Ellefson, 2000). One outcome of this failure, however, was that states responded by adopting their own regulations of forestlands.

A second outcome was that Congress has moved away from command-and-control approaches to land-use management.

A review of bills introduced in the 106th and 107th U.S. Congresses (four years, from 2000 to 2004) revealed that during that time more than 50 uniquely numbered pieces of legislation directly or indirectly addressed carbon sequestration (Richards, 2004). A representative selection of recent bills (Table 6) suggests that Congress has turned to government provision of information and incentives and voluntary initiatives for action in the private sector. With political constraints on the use of regulations and with government lands representing less than half of the U.S. land base, and far less of the nation's terrestrial sequestration potential (see discussion in following section), programs of the type represented by the two top rungs of the ladder in Figure 3 are likely to play a large role in federal efforts to promote carbon sequestration.

The top two rungs include several types of programs that provide landowners with financial incentives to undertake carbon sequestration; but under all of these programs participation is voluntary. Incentives can be used to encourage participation in both information-based and action-oriented programs. For action-oriented programs, incentives can be designed to be either practice-based or results-based. Incentives such as per-acre or per-ton subsidies, cost-sharing, land rental payments, or  tax advantages can be utilized. The financial burden of these incentives falls upon the federal treasury and taxpayers.

Practice-based incentives have been an important part of the USDA's program mix since the 1930s. The oldest USDA cost-sharing program, the Agricultural Conservation Program (ACP) provided cost sharing for such practices as grass and tree planting, timber stand improvement, and wildlife habitat improvements; practices which, among other benefits, sequester carbon. Under practice-based approaches, the government controls which practices are rewarded while private parties control whether and where to participate in the program. To increase carbon sequestration the government could, for example, increase availability of per-acre subsidies for planting trees on old fields or marginal agricultural lands. One drawback of practice-based approaches is that they limit the range of sequestration options that landowners can adopt, and hence may foreclose cost-effective sequestration opportunities.

To provide landowners with additional flexibility and incentives to search for low-cost sequestration practices, the government might shift up to the top rung of the ladder (Figure 3) where it rewards actual sequestration accomplishments. This would likely lower the per-ton cost of sequestration as landowners adapted practices to their local conditions. In general, landowners who are familiar with local conditions and particularly with the idiosyncrasies of their own land will be in a better position to innovate and to spot the best and most cost-effective sequestration opportunities than a centralized government agency employing uniform standards across diverse landowners and land types. However, rewards for reductions on a per-ton basis may increase administrative oversight requirements and increase monitoring and verification costs. Interest in finding cost-effective means to achieve environmental goals

***Table 6***

## Examples of Bills Related to Carbon Sequestration

**from the 106th and 107th Congresses**

| Title | Citation | First Sponsor | Type of Programs Established |
|---|---|---|---|
| The Energy and Climate Policy Act | 106 S. 882 | Murkowski | Government produces and disseminates information (**GPI**) Encouragement offered for Voluntary private Actions |
| Carbon Cycle and Agricultural Best Practices Act | 106 S. 1066 | Roberts | GPI; Practice-Based Incentives (i.e., based on adoption of practices) are offered for private party actions (**PBI**) |
| Climate Change Tax Amendments of 1999 | 106 S. 1777 | Craig | PBI |
| Credit for Voluntary Actions Act | 106 H.R. 2520 | Lazio | Results-Based Incentives (i.e., based on tons of carbon sequestered or emissions reduced) are offered for private party actions (RBI) |
| Carbon Sequestration Tax Credit Act | 107 S. 765 | Brownback | RBI |
| Carbon Sequestration and Reporting Act | 107 S. 1255 | Wyden | PBI |
| National Greenhouse Gas Emissions Inventory Act | 107 H.R. 4611 | Olver | Regulatory, Private parties supply information |
| Climate Stewardship Act of 2003 | 108 S. 139 | Lieberman | RBI |
| Healthy Forest Restoration Act | 108 H.R. 1904 | McInnis | Government undertakes carbon sequestration activities directly |

has spurred increasing exploration of results-based approaches. By providing rewards in proportion to the actual sequestration achieved—that is, in dollars per ton of carbon sequestered rather than dollars per acre for the adoption of certain practices—the government vests in the private sector almost complete control over what practices are employed and what lands are enrolled.

No policy tool is perfect. As the government works its way up the policy ladder, providing more discretion to private landowners to search for and adopt low-cost sequestration alternatives, it increases its monitoring costs. When the government bows to political pressure from landowners and adopts policy tools that provide incentives (practice-based or dollars per ton) rather than controls (regulations) or penalties (taxes), it increases the social costs due to the requirements for additional government revenue-raising. In the following sections, each of the four basic types of policy tools shown in Figure 4 is discussed and evaluated in further detail.

## B. The First Rung on the Policy Ladder: Government Ownership and Production

*The federal government is a significant landowner, but unfortunately its capacity to increase carbon stocks on current holdings is limited, and there is significant political resistance to the federal government acquiring large new holdings of land.* In contrast to the limited opportunities for direct production of carbon stocks on government land, there are significant opportunities for the government to provide information-related services. Opportunities also exist for preserving existing carbon stocks on government lands, particularly through efforts to decrease highly destructive forest wildfires.

The federal government owns approximately 29 percent of all land in the United States; another nine percent is owned by other government entities. However, the federal government's capacity to store carbon on current holdings is limited due to several factors. First, much federal land is very low in production capacity, so changes in management result in small, slow-responding changes in soil and stable biomass. Second, much of the land base is restricted by a variety of federal laws and priorities, so changing use or management is a formidable task with legal and organizational barriers. And finally, public opposition to altering federal land management in major ways will create significant political obstacles.

A government production approach, the first level in the policy ladder of Figure 4, is reflected in many legislative proposals and current programs. For example, the Forest Resources for the Environment and Economy Act (107 S. 820) would have required the USDA to quantify the amount of carbon stored in the National Forest System and to assess the potential for increasing that amount while providing "positive impacts on watersheds and fish and wildlife habitats through forest management actions."

It is difficult to fully evaluate the opportunities for increasing carbon sequestration on federal lands because the data available for federal land resources are significantly less robust than the data available for non-federal lands. The two main periodic surveys most relevant to evaluating carbon sequestration potential are conducted by the USDA: the Forest Information and Analysis (FIA) conducted by the Forest Service, and the National Resources Inventory (NRI) conducted by the Natural Resources Conservation Service. Neither survey covers federal lands effectively.[11] Forestland data extracted from the tables generated for the 1997 Resources Planning Act (RPA) study (www.fs.fed.us) provides estimates of federal timberlands and other federal forest areas (Table 7).

The government owns almost no agricultural land, so sequestration efforts on public lands are likely to focus on forests. Because so much of the forestland in the federal system is reserved for uses other than timber, the potential for changing management practices on federal forestland is limited to about 100 million acres, largely in the National Forest System (Table 7). In timberlands, several possibilities for increasing carbon sequestration exist, although there is little if any data to quantify their potential.

***Table 7***

## U.S. Federal Forestland Area in 1997 (in thousands of acres)

| Agency | Total Forest[1] | Timberland[2] | Other Forest[3] |
|---|---|---|---|
| National Forests (Forest Service) | 146,777 | 96,435 | 50,342 |
| Bureau of Land Management | 33,986 | 6,143 | 27,843 |
| Other Federal[4] | 65,958 | 6,590 | 59,368 |
| **Total** | **246,722** | **109,168** | **137,553** |

Source: Tables 2 and 10, 1997 RPA, USDA Forest Service.

Notes:

[1] Forest is defined as an area larger than one acre in size, with more than 10 percent tree cover.

[2] Timberland is defined as forestland that is biologically capable of producing more than 20 cubic feet of merchantable wood per acre per year, and is not restricted from timber production.

[3] Other forest is either productive forest reserved for other uses (i.e., national parks, designated wilderness, etc.) or is land that is too unproductive to meet the timberland definition.

[4] Other federal landowners span a variety of agencies, including but not limited to the National Park Service, U.S. Fish and Wildlife Service, Department of Defense, Department of Energy, etc. The ecological character and management limitations of these lands are contained in agency or location plans, but are not readily available in summary form. To get some idea of the potential for increased carbon sequestration on these lands through management, however, it is instructive to note that half of the "other forest" lands in federal ownership (over 62 million acres) is in Alaska and most of the rest (over 51.6 million acres) is in the arid or high-elevation regions of the Intermountain West.

One possibility rests with the remaining old-growth forests, which occur largely on the western side of the Cascade and Coast mountain ranges of the west coast. There, protecting old-growth forests from conversion to shorter-rotation production systems can maintain high volumes of on-site carbon (Harmon et al., 1990). However, those protections are largely in place today as a result of federal policies adopted over the past decades for other reasons, e.g., to protect endangered species such as the spotted owl.

Another opportunity exists in the drier forests of the Intermountain West (the area between the Cascade and Coast ranges on the west and the Great Plains on the east). This huge, diverse area contains almost 100 million acres of federal forests where a century of fire suppression has resulted in significant biomass buildups on the land (see Box 2, page 17). Recent policy changes and budget authorizations have dramatically increased federal agency efforts to carry out fuel-reduction projects on this land—thus reducing risks of highly destructive fires with their attendant large losses of carbon stock. However, with some 40 million acres at risk, the task will take years, if not decades, to complete (Hardy et al., 2000). While federal land holdings are fairly small in the eastern United States, the regrowth of the eastern hardwood and southern pine forests has contributed to a steady increase in forest biomass since 1952 (Powell et al., 1993). However, these increases are predicted to slow in the 21$^{st}$ Century as the forests reach maturity.

As limited as the data are on federal forests, they are far more limited on the non-forested federal lands (desert, alpine areas, brushlands, grasslands, etc.). In most cases these lands, largely in the West and Alaska, are too unproductive to be capable of sequestering significant additional quantities of carbon. Some creative ideas have been proposed, such as growing salt-tolerant crops using saline water for irrigation, harvesting the resulting biomass, and either incorporating it into (or with) desert soils where it would last for decades before decomposing, or using it as an energy feedstock to replace fossil fuels (Glenn et al., 1993). A few such projects are in the research stage, but none have been expanded to production scale, and it is still uncertain whether or when they may become feasible.

### *Cost and Environmental Effectiveness*

Government production of carbon sequestration is relatively easy to implement and entails low monitoring and enforcement costs. The cost of a program in which the government was responsible for increasing carbon on government-owned lands would fall squarely on taxpayers with the attendant costs associated with increased demand for government revenues.[12] To maintain or increase carbon stocks on its own lands, the government can either adopt a sequestration target and appropriate funds sufficient to achieve that goal, or it can set a funding level and seek to accomplish as much carbon sequestration as the funds permit. While there are only limited opportunities for the government to create and expand carbon stocks, government action to preserve existing carbon stocks, particularly through efforts to decrease highly destructive forest wildfires, is likely to be both more effective and more feasible from a political and physical perspective. Preserving carbon stocks through fire control has the added benefits of protecting people, structures, and communities from fire damage, thereby preventing significant economic losses. As a result, forest fire prevention programs are hugely popular and comparatively well funded. Introducing fire back into ecosystems is more problematic, as it involves direct costs to agencies as well as the risks of loss of control of fires and the health impacts of smoke. But fuel management programs can effectively address these risks in most cases, and the accompanying benefits—in terms of healthier forests, improved wildlife habitat, enhanced biodiversity, and the reduced risk of uncontrollable wildfires—are significant.

Advances in carbon sequestration also hinge on education, research, and the dissemination of information. Indeed, governmental opportunities to provide information-related services such as education and research are, like efforts to preserve existing stocks, likely to be more significant, effective, and politically feasible than the opportunities to directly increase carbon on federal lands. Education can include providing technical assistance to individuals, producing and distributing educational materials, as well as holding conferences, workshops, tours, and classes (Baughman, 1993). The USDA, for example, has historically provided information through its research, extension, and education programs. These programs have included technical assistance to assure quality control and to avoid the use of public funds on ill-advised projects.[13] In practice, these educational programs are carried out largely by State Land Grant Universities and Cooperative Extension Services. The Natural Resources Conservation Service (NRCS), in cooperation with local soil and water conservation districts, is also involved in educating landowners. Recently USDA has also begun to provide information relevant to carbon sequestration on the web. State forestry agencies implement most of the educational portion of the forestry programs administered by the U.S. Forest Service. Other government departments that undertake research and information dissemination include, for example, Oak Ridge National Laboratory, which had an active program of carbon sequestration research, and the National Energy Technology Lab, which continues innovative sequestration work. Finally the U.S. Environmental Protection Agency actively provides information on carbon sequestration to the public through its website and conferences. There are also a number of relevant private educational initiatives.[14]

## C. The Second Rung on the Policy Ladder: Regulatory Programs

*In the United States, state and local governments have used regulatory programs to direct forestland practices, and increasing regulation of private forest management seems likely.* The multitude of governing bodies involved in regulating forestlands results in program coordination challenges at the state level and confusion on the part of landowners. Most early state laws governing forestry practices were a reflection of the concern for improving forest harvest and regeneration practices, as well as a demonstration that states could regulate private land use in ways that the federal government could not. New environmental legislation at the federal level during the 1970s and growing public concern about the environmental impact of forestry practices led several states to enact broader and more comprehensive legislation (Ellefson et al., 1995; Ellefson, 2000).

As of 1992, 38 states had at least one program regulating forestry practices on private lands. Ten states had comprehensive forest-practice regulatory programs based on individual acts, while three states had a cluster of separate but complementary acts that constituted a comprehensive program (Ellefson et al., 1995). The effect by 1995 was that about 22 percent of privately-owned timberland was subject to a state regulatory program. By 2000, nearly 40 percent of private forests were subject to state regulation, affecting an estimated 135 million acres (Ellefson, 2000). Not only is the scope and range of state forest regulation growing, so is the variety and type of public bodies involved. In a 2000 survey, Ellefson et al. (2002) identified 356 cabinet-level agencies, 652 sub-cabinet agencies, 197 bureaus and offices, and 248 governing and advisory bodies that had regulatory influence over private forest activities. In addition to state forestry agencies, public authorities involved in forestry issues may include pollution control agencies, departments of agriculture, departments of health, and many other agencies. This can be a challenge for program coordination at the state level and can result in some degree of confusion on the part of landowners and the general public (Ellefson et al., 2002).

In addition, private forest certification programs in the United States are increasingly having the effect of "leveraging" state programs. Participants in the largest certification program in North America, the Sustainable Forestry Initiative (SFI), are required to implement all state-adopted best management practices (BMPs). For example, BMP for water quality protection are voluntary in some states, mandatory in others. But participants in private forest certification systems are required to comply with them, whether voluntary or mandatory (AF&PA, 2002). This has the effect of making the protection of water quality, prevention of soil erosion, and reforestation of harvested forestlands a requirement for the 150 million acres of private U.S. forestland that are enrolled in the program. In addition, a 2002 requirement that SFI participants encourage similar actions on all the private forestlands from which they purchase timber makes sustainable forest management a higher priority for virtually all private forestland owners. While these private programs do not have the force of law, they are important in affecting landowner decisions because they target a critical point in the forest management cycle—the harvest and regeneration period. Since the SFI program affects some 90 percent of the industrial forestland in the U.S., and its members purchase most of the timber processed in the country, it is estimated that it now affects the way forestry is practiced on nearly half a billion acres in the United States and Canada (AF&PA, 2005).

In addition to state regulations and private certification programs, many local ordinances regulate forestry practices. Where these have proliferated in the absence of a comprehensive state regulatory framework, the issue may become whether a patchwork of local regulations is preferable to an overall state framework administered by one agency (Ellefson, 2000). Given the long history of state and local regulation in forestry, and the growing public concern over environmental issues and sustainable development, increasing regulation of private forest management seems likely.

### *Cost and Environmental Effectiveness*

The carbon and cost effectiveness of regulatory efforts has been difficult to measure, and indeed may not be measurable. Estimating absolute changes in carbon stocks is straightforward. However, estimating program results is more challenging due to the difficulty of determining the causes of the changes. Figure 1 (page 2) indicates that changes in carbon stocks are a result of at least three different forces: (a) background changes in land-use trends, markets, natural conditions, and technologies; (b) changes related to ongoing government forestry, agriculture, and environmental programs; and (c) changes arising from programs and policies targeted at carbon stocks. Since there is interaction among the three influences, any increases in carbon sequestration may be partly driven by government programs designed for other purposes, partly by forest regulations, and partly as a result of shifts in background factors.

To separate the effects of forest regulations from other factors requires establishment of a baseline or business-as-usual forecast for carbon sequestration. This is a complex task that can involve sophisticated economic and forestry models (Kerr et al., 2003, Sohngen and Mendelsohn, 2003). Methods for establishing baselines for evaluation of national carbon sequestration programs are still being developed. Once developed, it is possible that these methods could be applied or adapted to evaluate the effects of state-level programs. In any case, further work in assessment of program effectiveness is needed.

Cost-effectiveness studies have been few and inconclusive (Cubbage, 1996). In the ten states with comprehensive laws governing forestry practices, lead agencies spent $21.9 million in 1991—an amount that had more than doubled since 1985. While regulatory program administration budgets increased about twice as fast as total forestry budgets, regulation still accounted for less than 4 percent of total state expenditures on forestry activities in these ten states (Ellefson et al., 1995). Most of the state expenditures on regulatory programs are for administrative costs (permit issuance, etc.) and field compliance checks by state forestry employees.

The costs to landowners of complying with regulatory requirements can be significant as well. In California, the average cost of hiring a registered professional forester to prepare a timber harvesting plan was above $11,500 in 1992, and special surveys can double that figure (Henly, 1992). Obviously, these costs discourage small timber sales, and raise the possibility that small owners may need to band together to develop plans. Costs are also incurred in meeting the on-the-land requirements imposed by regulations. One five-state review of 18 harvesting operations in the Midwest found that complying with water quality protection regulations reduced net revenue by an average of $73,500 (from $124,300 to $50,800) for the average landowner (Ellefson and Miles, 1985). A study in southern states found the cost of implementing water quality practices reduced gross harvest revenues per timber harvest by an average of $58,864 (Lickwar et al., 1992). Since a reduction in gross revenue translates directly into a similar reduction in net revenues, the findings of the two studies are comparable.

In discussing the costs of regulatory programs, however, it is important to note that voluntary approaches may impose costs of a similar magnitude, both to government and to the private landowner (Cubbage, 1995). This will be particularly true where landowners are expected to achieve the same results, or apply the same practices. If the BMPs require similar effort, the costs will be the same for those who comply with them regardless of whether the state BMPs are voluntary or mandatory. The voluntary approach may allow more flexibility, which may achieve similar results with lower costs in some cases, but the differences may be less than political arguments would suggest.

## D. The Third Rung on the Policy Ladder: Practice-Based Incentives

*Provision of direct financial assistance to landowners has been an important part of USDA's program mix since the 1930s.* Historically, the USDA cost-share contracts and subsidies have proven popular mechanisms for engaging the private agricultural and forestland owners who hold approximately 60 percent of the land in the United States and 70 percent of the land in the contiguous states.

The important role that the USDA will play in any future national carbon sequestration effort is reflected in the many programs that were created or expanded in the Farm Security and Rural Investment Act of 2002, also known as the 2002 Farm Bill. The 2002 Farm Bill made important additions and changes to agricultural conservation and forestry programs (see Table 8). In virtually every case, program objectives were expanded to include carbon sequestration as an activity that could qualify for federal

***Table 8***

**USDA Programs Created or Expanded in the 2002 Farm Bill**

**(USDA-FSA 2002)**

| Program | Function | Agency | Changes in 2002 |
|---|---|---|---|
| Environmental Quality Incentives Program (EQIP) | Cost-sharing, technical assistance | NRCS, FSA | Re-authorized to 2007; funded with $5.8 billion in CCC funds. Non-industrial forestland made eligible |
| EQIP Innovation Grants | Grants for innovative approaches (includes carbon sequestration and connection to market mechanisms) | NRCS | New program element added to EQIP in 2002 |
| Conservation Reserve Program (CRP) | Cost sharing, land rental | FSA | Extended to 2007; acreage cap raised to 39.2 million acres |
| Conservation Reserve Enhancement Program (CREP) | Cost-sharing, land rental. Done in cooperation with states; program details vary state to state | FSA | Continued; minor changes |
| Forestry Land Enhancement Program (FLEP) (replaces FIP and SIP) | Financial (cost-sharing), technical, and educational assistance to private forestland owners of less than 1,000 acres | FS | New program; funded with $100 million in CCC funds through 2007 |
| Wildlife Habitat Incentives Program (WHIP) | Cost-sharing, technical assistance | NRCS | Re-authorized to 2007 |
| Wetlands Reserve Program | Cost-sharing, term (30 year) or perpetual easements | NRCS | Re-authorized to 2007; maximum acres set at 2,275,000 |
| Conservation Security Program | Cost-sharing for new or maintaining existing conservation practices | NRCS | New program; being tested on watershed basis |
| Sustainable Forestry Outreach Initiative (SFOI) | Education | CSREES | New program |

Agency acronyms: CCC – Commodity Credit Corporation; CSREES – Cooperative State Research, Extension, and Education Service; FS – Forest Service; FSA – Farm Services Agency; NRCS – Natural Resources Conservation Service.

educational, technical, and cost-sharing assistance. It should be noted, however, that currently these are rather blunt policy tools. Carbon sequestration is one of many goals, not the primary program focus, and there are no provisions for estimates of carbon levels achieved.

The oldest USDA cost-sharing program, the Agricultural Conservation Program (ACP), provided cost sharing for such practices as grass and tree planting, timberstand improvement, and wildlife-habitat improvements. Cost-share rates were generally around 50 percent. Studies of the program found that it was effective in encouraging landowners to plant trees and implement forest management practices, and that areas planted in trees under this program tended to remain in forest use (Kurtz et al., 1994).

Dwindling resources in the ACP program and its lack of focus on forestry concerns led to enactment of the Forestry Incentives Program (FIP) in 1973. FIP was aimed directly at timber production. A more recent effort—the Stewardship Incentives Program (SIP)—attempts to broaden the cost-sharing approach beyond timber to encourage more ecosystem-based practices and management. The Forest Land Enhancement Program (FLEP) replaced both of these programs in 2002, and continues the trend toward broader program objectives.

The largest land conversion programs were the Soil Bank Program of the 1950s and 1960s and the Conservation Reserve Program (CRP) of the 1980s to the present. Both programs were designed to address commodity surplus situations, both encouraged landowners to retire cropland and restore either grass or tree cover, and both provided cost sharing for initial implementation plus land-rental payments under contracts that generally ran 10 to 15 years. The CRP was directed specifically toward the retirement of marginal crop and pastureland to reduce soil erosion losses, so it had a more direct conservation focus than the Soil Bank. In its 16 years of operation, the CRP has had a major effect on America's farm landscape. The 1997 National Resources Inventory listed 32,697,000 acres of land in CRP in 1997 (USDA-NRCS, 2000). Table 9 illustrates the extent of CRP practices that are likely to sequester carbon in soils or wood.

Concern about the continued fragmentation of forestland into smaller and less manageable tracts as a result of economic and development forces led to the Forest Legacy Program in the 1990 Farm Bill. In this program, the Forest Service cooperates with states to negotiate and purchase permanent conservation easements on private forestlands. By 2004, the program had conserved over one million

*Table 9*

## Area of Conservation Reserve Program

**By Practice, for Active Contracts for All Program Years 1987-2003**

| Practice | Acres | Practice | Acres |
|---|---|---|---|
| Introduced Grasses | 4,327,016 | Tree Planting | 1,166,988 |
| Native Grasses | 6,239,811 | Wildlife habitat | 2,283,598 |
| Grass Waterways | 74,586 | Field Windbreaks | 42,326 |
| Established Grass | 14,957,376 | Established Trees | 1,037,816 |
| Wildlife Food Plots | 68,976 | Shelterbelts | 20,651 |
| Filter Strips | 31,829 | Riparian Buffers | 427,120 |
| Contour Grass | 60,944 | Wetland Restoration | 1,840,298 |

Source: U.S. Department of Agriculture.

acres, with a value estimated at over $361 million, for a program investment of $183 million in federal funds (USDA-FS, 2004).

All of these programs provide subsidies for specific practices. However, it is also possible to use taxes to implement practice-based programs. For example, one can imagine a program that would assess a fee on landowners who clear their land of forests and do not replant within a specified time. Relative to subsidies, taxes have the advantage of decreasing the amount of revenue the government must raise, and thereby decreasing the public finance burden. However, proposing new taxes always entails a substantial political risk. Alternately, if a cap-and-trade program were established, emission credits could be awarded to encourage desired practices.[15] Rather than paying subsidies for adoption of specified practices, the government could provide rewards in the form of credits that could be sold to entities to assist them in meeting their obligations under a cap-and-trade program (see Section E for further discussion of cap-and-trade approaches). For example, the government could provide credits of one ton per acre per year for landowners who convert their cropland to forest stands and agree to maintain them for fifty years.

### *Cost and Environmental Effectiveness*

As discussed in connection with regulatory programs, measuring the carbon sequestration benefits of subsidy programs—and therefore their environmental effectiveness—will be challenging. In addition to the difficulties involved in ascribing carbon results to specific programs, the length of time over which carbon stock increases are maintained (their "permanence") plays a role in environmental and cost-effectiveness. The costs and cost-effectiveness of practice-based incentive programs also depend on the extent to which payments can be targeted to maximize carbon gains per dollar spent. These issues are discussed below.

### *Measurement of Carbon Stock Changes*

The United States measures changes in carbon stocks at the national level, and, under the United Nations Framework Convention on Climate Change, reports aggregate rates of carbon sequestration based on changes in national carbon stocks. For example, the 2002 U.S. Climate Action Report estimated that the net increase in terrestrial carbon stocks in the United States was 270 million metric tons per year. To estimate national carbon stocks, the government draws on several sources.

For forest carbon, the U.S. Forest Service has maintained the Forest Inventory and Analysis (FIA) program since 1928. The FIA has produced comparable national inventories since 1952 (Powell et al., 1993). In the past, the FIA only inventoried private forestlands, and was carried out on a roughly 10-year cycle, although in some states the interval between inventories has been as long as 15 years. In part because of the increased national interest in trends in carbon sequestration, and in part due to other forest conservation issues, the FIA program has recently been upgraded from a 10-year inventory cycle to a 5-year cycle, with 20 percent of the area inventoried each year (Gillespie, 1999). The new inventory will also include both private and public forestlands. In addition, new sampling will capture attributes such as soil carbon and forest-floor carbon, including deadwood, that will add statistical accuracy to national estimates of carbon stocks. Full implementation of this enhanced inventory program is anticipated by 2008 (Heath and Smith, 2002).

For estimates of carbon on non-federal (including state and local) crop and grasslands, National Resource Inventories (NRIs) are the primary source of data. These inventories (which do not include Alaska) are carried out by the USDA's Natural Resources Conservation Service on a 5-year cycle. The inventories rely on a statistically established set of fixed plots that are sampled for a variety of characteristics, including land use, management, and soil characteristics. National-level land-use and management changes are used to estimate associated effects on carbon stocks. For agricultural soils, a combination of data from the NRI on cropland use and localized information about tillage and cropping practices are fed into the CENTURY model, which then predicts changes in soil organic carbon content (Brenner et al., 2002). Collection of additional, more specific information on management practices, plus measurement of soil carbon at a subset of NRI plots, would greatly improve the accuracy of model results. (See Paustian et al., 2006 for further discussion of this issue.)

There is at present no inventory of federal lands comparable to either the FIA or the NRI. Current estimates of carbon stocks on federal lands are derived from analysis of very coarse land-cover data from satellite imagery and general estimates of the carbon stocks of various types of cover. By 2008–2010, the new FIA program may provide estimates of carbon stocks on federal lands that are statistically comparable to those now available for non-federal lands.

Based on the inventories and models mentioned above, the USDA reports estimates of absolute changes in carbon stocks; it does not identify causes for these changes. Determining the extent to which any given change is the result of carbon sequestration programs and policies will be significantly more challenging.

***Maintaining Environmental Gains (Permanence)***

Another issue that emerges in considering the effectiveness of practice-based incentive programs is permanence. It has been suggested that both cost- and environmental-effectiveness of carbon sequestration programs could be reduced because stored carbon can be released back into the atmosphere. However, while permanence or duration has become a much-discussed issue in carbon sequestration projects, the concern is not new to conservation programs. Practices designed to limit soil erosion and/or water pollution also need to be maintained or their benefits can be lost. Management practices need to be consistently pursued and physical infrastructure (e.g., terraces or grassed waterways) need to be properly maintained. Various approaches have been used to address the problem of permanence. For example, the government has used payback clauses in some of its cost-sharing programs such as the Environmental Quality Incentives Program (EQIP). Under a payback clause producers agree to maintain a practice for a normal life span (usually determined by the local technical guide) or pay back the federal dollars received. This approach, of course, places the burden on the government to monitor that the management practice has continued and to collect any repayments that may be due if the agreement is violated.

An alternative to the payback clause is a long-term contract based on conservation plans. The Great Plains Conservation Program, for example, was based on long-term contracts between the producer and the federal agency (now NRCS). These long-term contracts were generally judged to be effective and are still a feature of programs such as CRP and EQIP. One of the major advantages of the long-term contracts is that they provide the stability needed to fund all elements of the landowner's conservation plan, which may need to be implemented over the course of several years. (See Paustian et al., 2006 for a discussion of costs of long-term contracts for soil carbon.) Under annually funded conservation programs, a delay in Congressional appropriations can cause major disruptions in project implementation. Practices such as tree planting, for example, must be carried out at the appropriate time of year (usually late fall or early spring, depending on the area's climate and soils). When cost-sharing funds are not available until after the planting season, or are not available at all in a particular year, planting may be delayed for a full year. The disruption affects not only the planned planting but leaves nurseries with excess stock that must be destroyed and contractors without planned work or income.

***Targeting Strategies***

The USDA subsidy programs can involve large government expenditures. To contain costs and increase cost-effectiveness there have been ongoing attempts to target conservation and forestry programs, both to landowners that are most in need of assistance (financial targeting) and to lands where the most conservation benefit can be gained (environmental targeting). These efforts have had mixed results.

Two methods of financial targeting have been tried: limiting payment amounts and applying "means" tests. In some federal land-use programs, financial benefits have been limited to a specified annual amount per producer to target recipients most in need of incentives. As costs for some types of practices (e.g., animal-waste management systems) rose, these limits became an obstacle to achieving program goals. In cases where the landowner truly needed federal assistance to adopt the new practice, the landowner might resist investments that exceeded the assistance limit. As a result, subsidy limits under various programs have been raised significantly over the years (e.g., to $450,000 per producer for 2002–2007 under the EQIP program), to the point where it is doubtful whether today's limits provide much of a positive targeting effect. The other approach, a "means test," has been used in some cost-share programs like the ACP. This program requires an applicant to certify that they would not be able to implement the practice without federal assistance. Those certifications were routinely signed by producers on the basis that, without federal help, they would choose not to go ahead. The difficulty of proving intent—i.e., what an individual or entity would have done in the absence of a carbon payment—is a lesson that has been re-discovered in the context of carbon sequestration credits.

In the context of GHG emission reduction programs, it has been proposed that credits be awarded only for carbon sequestered (or emissions avoided) in "addition" to what would have happened in the normal course of business. This has created a debate as to whether "financial additionality" is an appropriate or viable test; i.e., can it be determined whether a project is financially viable on its own merits (would have occurred in the normal course of business) or requires carbon incentives to be carried out (i.e., qualifies as "additional")? In general, even the most scrupulous landowners will have little trouble justifying a statement that they would not have proceeded with a project "but for" the additional benefits or incentives provided by a government program.

Targeting payments to achieve the most environmental benefit (environmental targeting) has also been tried. Where the government is providing incentives to encourage carbon sequestration, it will get the most "bang for the buck" if it is able to provide incentives where they will achieve the greatest increases in carbon stocks per dollar spent. However, just as it can be difficult to target the landowners most in need of financial aid, it can also be challenging to target the most cost-effective situations or applications. A proposal during the Reagan Administration to limit forestry technical assistance to landowners above a certain size met with opposition and was never fully implemented. This proposal was intended to maximize timber output per dollar of federal investment, but by systematically eliminating the vast majority of forestland owners from the programs, it was feared that political support for improving forest management (which was never very strong) would be decimated.

A major effort to target program resources to the most serious soil erosion situations was launched in 1985, when critics pointed out that much of USDA's technical assistance and cost-sharing was being directed to areas where soil erosion studies indicated lesser problems. Local conservation-district officials, however, strongly resisted the effort to target resources on the most serious problems, arguing that it would often penalize effective programs while rewarding "bad actors." In the context of carbon sequestration it has been proposed that payments would only be provided to "new adopters" of carbon sequestering practices or for carbon stored after the effective date of the program. As in the soil conservation context, targeting new carbon sequestration has been criticized for penalizing "good actors", i.e., early adopters of practices that increase carbon, and rewarding "bad actors." Those who had already adopted carbon-sequestering practices, or had already stored carbon, would not qualify for payments for carbon stored, while those who had not yet adopted desirable practices would qualify for payments. (See Paustian et al., 2006 for a discussion of costs of paying only new versus all adopters.)

Past experience indicates that it is at best a difficult process to differentiate between those who would have undertaken a particular practice or project in the absence of an incentive and those for whom the incentive was the deciding factor. Experience also suggests that rewarding only new adopters or large landowners may prove politically difficult. This does not suggest that using practice-based approaches to carbon sequestration will yield no gains in carbon stocks or will yield gains only at prohibitive costs. It does, however, suggest that costs may be higher than estimated in typical cost-effectiveness models. Concomitantly, programs will likely have less effect on carbon stocks than might be surmised based on program expenditures and landowner claims. The difficulty of targeting incentives suggests that the U.S. government should invest substantially in careful program evaluation to estimate the actual impacts of its investments in carbon sequestration.

## E. The Fourth Rung on the Policy Ladder: Results-Based Incentives

*The key advantage of results-based approaches is that they provide private parties with a great deal of flexibility in pursuing sequestration goals and could minimize costs.* Results-based approaches allow for innovative approaches customized to local circumstances and create incentives that closely coincide with the sought-after outcomes. There are two basic results-based approaches for including the forest and agricultural sectors in a climate mitigation strategy: direct and indirect. The direct approach is for the government to deal with landowners by establishing contracts or providing subsidies for specified amounts of carbon sequestration, or even taxing releases from carbon stocks. For example, a landowner who clears a forest and does not replant could be assessed a fee in proportion to the estimated carbon losses. Where the results-based subsidy rewards beneficial carbon sequestration changes, the results-based tax would penalize or discourage undesirable changes. Like the practice-based tax, the results-based tax has desirable properties in terms of revenue raising, but carries with it a substantial political liability. The direct approach is not predicated on any particular assumption about emissions control programs and can therefore operate independently of a wider program to control GHG emissions from fossil fuels.

The indirect approach involves a program operated as a part of a cap-and-trade system. Under this system, emission limitations (caps) are placed on utilities, manufacturers, and other large sources of emissions. Those covered under the "cap" (capped sources) can choose whether to reduce their emissions or purchase credits from others. The program could be designed in such a way that the government issues credits to landowners for carbon stock gains and emission reductions achieved through projects on their agricultural and forestlands. For example, a landowner who demonstrates a 100-ton increase in carbon stocks might be granted 100 tons of credit. Landowners would be allowed to sell these credits directly to capped entities. Capped sources would be allowed to purchase and use these credits to assist in meeting their emission limitations, purchasing the credits either directly from landowners or from intermediaries. If credits are issued to individual landowners, mechanisms to evaluate the benefits of specific projects must be developed. An alternative program design would be for the government to sell directly to capped sources credits based on changes in national carbon stocks (Andersson and Richards, 2001). Whichever program design is used under the indirect approach, the market would determine the monetary value of credits. The indirect approach also allows the government to set an overall net emissions reduction goal and meet it using whatever combination of sequestration increases and emission reductions is least expensive.[16]

The direct and indirect approaches are not necessarily mutually exclusive paths to promoting carbon sequestration. For example, it is conceivable that the government could establish a practice-based or a results-based payment program for carbon sequestration before there is a cap-and-trade program for emissions. Then, when a cap-and-trade program is established, the sequestration program could be easily subsumed into it. To make the transition, government could change from providing cash (in dollars per ton) to providing credits (in tons of sequestration) that can be sold to capped sources.[17]

It has been argued that, if the federal government provides cost-sharing to a private landowner for conservation work that produces some carbon sequestration as one of many objectives, the landowner should not be allowed to sell or trade the carbon “credits” if a market emerges. The charge is that this would amount to double payment. Currently, however, the USDA policy is that their cost-share and long-term contracting programs such as the Conservation Reserve Program are designed and administered to pay for soil erosion control, water quality protection, and commodity production control. If farmers can sell other environmental services on the market, they are free to do so.

Current conservation and forestry cost-share programs do not pay for the measuring, monitoring and independent third-party verification that will probably be a necessary component of an emission credit program based on carbon sequestration (WRI-WBCSD 2003). In addition, in some conservation programs there is no requirement for maintaining forest practices for a specified time period. Thus, it may be possible that landowners in the future could face a choice. They could accept payments in a practice-based cost sharing program offered by USDA, in which case the amount of sequestered carbon would be estimated by the government for inclusion in the national reports. Alternatively, if higher payments are offered under a cap-and-trade program, farmers could accept measuring, monitoring, and verification systems, and more stringent contract requirements, such as providing guarantees for maintenance of carbon. In the end landowners will likely opt for the approach that provides the greatest return on their investment.

### *Cost and Environmental Effectiveness*

Any results-based approach will place additional requirements on the measuring and monitoring elements of a sequestration program. Moreover, experience with voluntary reporting of emission reduction projects suggests that monitoring and measuring may be needed for large numbers of small projects and projects spanning many orders of magnitude in size. Under practice-based programs, the government monitors compliance largely through self-reporting and visual inspection. Under a results-based approach, the government and program participants must employ some mechanism to estimate, report, and verify the actual carbon sequestration achieved by land-management and use changes. To engender popular and political support—particularly if credits that can be used to meet obligations under a cap-and-trade program are allocated to individual landowners—it will be necessary to develop procedures that assure the public that estimates of carbon gains represent actual gains.

#### ***Lessons from Voluntary Reporting***

Since 1994, the U.S. Department of Energy has maintained a database where parties can record their GHG emission reductions efforts. This database was created under Section 1605(b) of the 1992 Energy Policy Act, and it is important to understand that the guidelines for this voluntary program were deliberately designed to encourage participation rather than to ensure analytical rigor. As a consequence, the data reported in the 1605(b) database are of limited use in estimating the actual impact that projects have had on net emissions. The information in the database is useful, however, for another purpose: it indicates the type, size, and number of forest and agricultural activities that might potentially be involved in a results-based program. In this respect, several observations are instructive.

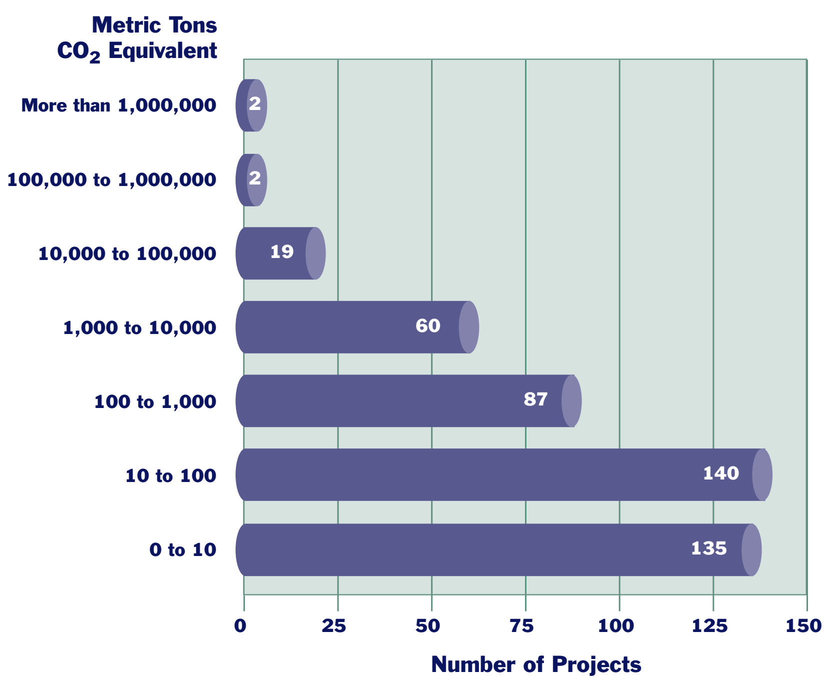
First, in 2003, the database recorded 2,188 projects from 234 reporting entities. Of these, 446 projects were reported in the "carbon sequestration" category by 51 different entities. According to database summaries, carbon sequestration projects accounted for 2.1 million tons of net carbon emission reductions compared to 72.4 million tons for non-sequestration activities. Of the 2.1 million tons of carbon sequestration, 89 percent were for foreign projects. Virtually all of these reductions were reported for five large forest preservation projects; as a result, just 10 percent of all reporting entities accounted for 92 percent of the total sequestration reported in 2003.

Second, the carbon sequestration projects in the 1605(b) database almost all involve forestry projects, the vast majority of which entail preservation, conservation, and afforestation or similar tree-planting activities (Brown et al., 2000). While only 39 of the projects reported are based on forest preservation, those few projects account for 88 percent of the total carbon sequestration reported. Third, based on annual carbon increments reported in 2003, the size of the projects spans six orders of magnitude, from a fraction of a ton of carbon sequestered per year to 1.13 million tons per year, with the two largest projects accounting for 81 percent of all reported carbon sequestered in that year (Figure 4).

It is impossible to extrapolate from the 1605(b) voluntary program to a national sequestration program with substantial monetary incentives. Incentives might encourage a wider range of sequestration projects, including management changes on agricultural and grazing lands, than is reflected in the 1605(b) database. Nevertheless, experience to date would suggest that a national carbon sequestration program could include a large number of small projects if they were allowed. In the 1605(b) database, even a project that captures only 10,000 tons of carbon per year is in the top 5 percent of all

***Figure 4***

**Carbon Sequestration Projects** Reported to 1605(b) by Amount of Carbon Sequestered, 2003




Source: http://www.eia.doe.gov/oiaf/1605/vrrpt/figure_12.html.

Note: One metric ton $CO_2$ equivalent = .27 metric tons of carbon.

sequestration projects by size. Thus, the first important lesson from the 1605(b) experience is that a government sequestration program may be dealing with many thousands of projects with sizes spanning many orders of magnitude, but with most concentrated in the low end of the size range. Moreover, if they are allowed, international projects will likely account for a very large amount of the carbon sequestration reported. Similarly, forest preservation projects, if they are allowed, may account for a disproportionately large amount of the carbon sequestration reported.

The second important lesson from the 1605(b) experience is that in the absence of financial incentives for carbon sequestration there is unlikely to be a large number of projects, and the amount of carbon sequestered will be relatively small. While public recognition and government encouragement may be sufficient to induce a few parties to develop projects, it will likely take significant subsidies, contracts, or value derived from an active carbon market to create a substantial response.

***Measurement Issues***

To implement a results-based program a number of issues must be addressed. Evaluation of the results from land-management and use changes involves several components, including measuring changes in emissions or carbon stocks at the project site, developing reference cases or baselines, and evaluating off-site or secondary effects. While there is virtually unanimous agreement that on-site carbon changes can be measured and monitored with both accuracy and precision,[18] there is less consensus regarding the development of reference cases and the evaluation of off-site effects (Richards and Andersson, 2001). These exercises are integral to results-based approaches.

The U.S. Department of Energy has revised the 1605(b) Guidelines for Voluntary Reporting of Greenhouse Gas Emissions and Emissions Reductions that provide the basis for attributing GHG reductions to individual entities and their projects (Federal Register, 2002, 2003, and April 21, 2006). In the original guidelines, both the development of reference cases and the evaluation of off-site effects were dealt with flexibly. Carbon sequestration was counted from the initial reporting date, and effects outside the reporting entity's control did not have to be included in the report. The new guidelines contain prescribed methods for measurement, and entities can select the method to be used. This approach was considered important for making the reports more consistent while maintaining a process that would attract potential reporters who faced weak economic incentives for participation.

What effect the revised 1605(b) voluntary reporting guidelines, released by USDOE on April 17, 2006, will have on the rigor of the reports and the willingness of agriculture and forestland owners to participate is still unknown. The USDA has developed several tools to aid in estimating carbon sequestration amounts from a variety of practices, but there are still questions regarding how the final guidelines will be perceived by small producers. The policy guidelines and the record of public comment, which illustrates many of these issues, are available at http://www.pi.energy.gov/enhancingGHGregistry/.

### *Measurement of On-Site Carbon Changes*

A variety of well-developed and relatively inexpensive methods are available for measuring on-site changes in carbon stocks in forests and agricultural soils. These methods have been developed by soil scientists, foresters, and ecologists over the course of many years. While traditional methods for measuring carbon in forests and soil are rather labor-intensive[19] and can be relatively costly, new quicker and more cost-effective methods are being developed. For example, remote systems that collect aerial digital imagery at very high resolution (10 cm pixel size), enabling measurement of individual trees, have been shown to produce accurate and precise estimates of the carbon stocks in live forest vegetation at costs one-half to one-third the cost of conventional field methods (Brown et al., 2005). For soil sampling, one new method—laser-induced breakdown spectroscopy (LIBS)—reduces the costs compared to earlier methods (Cremers et al., 2001). No matter which method is used for monitoring forest and soil carbon, accurate and precise estimates of carbon at the field, farm, or regional level require statistically robust sampling designs (Post et al., 1999) and use of relevant models. See Paustian et al., 2006 for further discussion of soil measurement, sampling, and models.

The cost of field sampling and analysis is directly related to the number of plots required to adequately sample the area in question, which in turn is a function of the levels of precision and accuracy of the estimated change in carbon stocks required.[20] Work on existing carbon sequestration projects in the forest sector has demonstrated that estimates at the 95 percent confidence level[21] can be achieved with modest costs (i.e., less than 50 cents per ton of carbon) for projects of several thousand acres or more (Brown, 2002). Sufficient experience with sampling soils in existing agricultural-based carbon sequestration projects is lacking and thus monitoring costs are unknown. However, at least one report has provided an upper estimate of measurement costs that is as low as 3 percent of the value of the carbon credits (Mooney et al., 2004). As with many measurement and monitoring procedures, there are certain fixed costs that are independent of project size. This leads to economies of scale in monitoring and measurement. Practical experience to date demonstrates that bundling small projects can reduce per project costs significantly and still result in valid and transparent carbon estimates. Aggregating organizations could assemble portfolios of similar projects that could be submitted as one report with identifiable parts. Compared to a system in which each project is independently reported by a different party, aggregators would also be likely to provide reports that would be more consistent and therefore easier to audit. Thus, the cost of measuring and monitoring changes in on-site carbon need not be a barrier to small or large-scale sequestration projects.

One option for reducing measurement, monitoring and verification costs to landowners participating in results-based carbon sequestration programs would be to provide financial support for hiring a qualified private professional consultant. Consulting assistance has been a feature of the Forest Stewardship and Forest Incentives programs, and several states have initiated service charges for state foresters that are the equivalent of private fees (Sampson and DeCoster, 1997). Thus landowners can either hire the state foresters or a private consultant, and federal cost sharing under these forest programs will cover part or all of the costs. Since state and local agencies cannot expand their work force easily (and many are shrinking under budget pressure), the effect of federal assistance for consultants is to create additional work for private-sector consultants when these programs are expanded. The 2002 Farm Bill also allows USDA to pay the cost of third-party, private, technical service providers under soil and water conservation programs if the landowner wants to use them to audit reports of carbon sequestered. Third-party auditors would not have a financial interest in the projects or provide the primary project reports. Rather, auditors would simply certify that the reports submitted by the project developers comply with the measurement requirements of the program.

### *Measurement of Other Impacts*

Projects undertaken in the context of results-based programs should be evaluated for their net effect on carbon sequestration levels. In its most thorough execution, evaluation involves adjusting estimates of onsite changes for offsite effects, losses from the project over time, and any changes in other greenhouse gases caused by the project.

To evaluate on-site impacts of management or land use changes, the carbon measured at some time after project initiation is compared to the level of carbon levels that would have been present at that point in time in the absence of those changes. This comparison requires development of a reference case, sometimes referred to as a business-as-usual scenario (Bashmakov, I. and C. Jepma, 2001, Chapter 6). The challenge in development of a reference case is that it is hypothetical; it cannot be observed. Hence, developing the reference case requires the project evaluator to employ some combination of control plots, modeling, and conjecture—similar to what would be needed to evaluate the impacts of regulatory or subsidy-based state or national-level programs.

Different types of projects require different types of reference cases. For example, a project to afforest land that has been in agriculture for decades with very little change in carbon levels can credibly use the historic on-site carbon stock as the reference case for evaluating changes attributable to the project. In contrast, a project designed to preserve a forest in its current state by, for example, preventing deforestation, must employ a reference case that involves assumptions about the causes, extent, and timing of deforestation that are expected to occur if the project is not undertaken. Methods to develop reference cases are being developed; all involve analyses of past trends that are then projected into the future using a variety of models (e.g., Brown et al., 2006).

Evaluating the effects of a sequestration project also involves controlling for gains or losses off-site, over time, and among the various GHGs. These gains or losses are sometimes referred to as leakage. The reason to adjust for leakage is that it might reduce (or increase) the overall benefits of the project. Consider the case where agricultural land is converted to managed forestland. The on-site effects might be relatively simple to evaluate. However, the loss of the agricultural land could have the effect of increasing the value of agricultural land, which in turn could lead to conversion of other, existing forestland back to agricultural land (Murray et al., 2002; Marland et al., 2001). This countervailing effect must be considered in a full treatment of project impacts. Another example is the preservation of forests from timber harvesting. Here it is important to consider the mobility of lumbering activities or, in many areas of the United States, the mobility of residential development. Ending harvesting or conserving forests on one tract could result in greater pressure to harvest or develop other areas. The problem with evaluating leakage effects of this type is that the market signals from any one individual project may be too weak to discern within the economy as a whole. Land conversions involving a few hundred or even a few thousand acres (a typical scale for many projects) may create some market pressures that would lead to leakage, but like the pebble thrown into the ocean, the impacts are unlikely to be discernible, let alone measurable.

The off-site leakage effect described above can be thought of as *geographic* leakage. However, leakage effects can also occur over time (*inter-temporal* leakage, also referred to as lack of permanence). For example, the effect of a project involving conversion of agricultural land to forests depends on how long the trees grow and live. If the forest is burned, or the land is later re-converted to a non-forest use, the sequestration benefits would be lost. Similarly, preservation of existing forests decreases emissions only as long as the protection remains in place. Hence, where some or all of the effects of a project can be "undone" in the future, evaluation of project results or program effectiveness must take leakage over time into account, and program design must accommodate that possibility. Proposals to address the permanence issue include use of easements on project lands that prohibit future conversion to non-forest or non-agricultural use. Easements may need to be coupled with contracts to insure reforestation in case of losses due to fires, disease, or insects. Alternatively, contracts could require repayment of subsidies, or replacement of credits, to cover losses due to land use or practice changes that "undo" the gains for which the subsidies or credits were granted. Other proposals to address permanence include rental, temporary, or time-limited credits for stored carbon; and ongoing payments for maintenance of increases in carbon stocks.

The problem of inter-gas leakage is self-descriptive. In some cases, projects can lead to an increase in carbon stocks or a decrease in emissions of carbon while causing an increase in other GHG emissions such as nitrous oxide ($N_2O$), methane ($CH_4$), or $CO_2$ from combustion of fossil fuels (e.g., due to increased use of equipment). For example, nitrogen fertilization can increase forest growth (thus increasing carbon stocks) but lead to an increase in $N_2O$ emissions. These effects must be addressed by netting out the global warming impact of any increases in other GHG emissions from carbon sequestration benefits.

***Implications for Results-Based Programs***

The challenges presented by evaluating project impacts are not new issues. The original 1605(b) Guidelines for Voluntary Reporting of Greenhouse Gas Emissions and Emissions Reductions (USDOE, 1994) discussed options for establishing baselines and dealing with leakage. However, those guidelines were written to encourage, not burden, greenhouse gas mitigation projects and their reporting. As such they left much to the discretion of the project developer and reporter and explicitly accepted the fact that project reports might not provide accurate estimates of project effects. While this may have been acceptable in the case of a voluntary program in 1994, it would be highly problematic in a results-based program where sequestration projects receive tradable emissions credits or other substantial incentives.

If carbon sequestration is linked to a substantial results-based reward system, the incentive to abuse discretion in the calculation of impacts could be substantial. For example, if credits in a cap-and-trade program are selling at $30 per ton, a project reporter who can raise the estimated increase in carbon stocks from 3,000 to 4,000 tons per year will reap a financial reward of $30,000 annually. Some project developers will maximize their rewards by being more efficient and designing better projects. Others are likely to do it by telling better stories, selecting more advantageous baselines, or ignoring significant leakage.

From the standpoint of overall program design, the difficulty is that no one knows how serious the abuses would be in an actual system. If abuses turn out to be a minor problem, they could simply be viewed as the cost of doing business. If, however, "carbon fraud" proves to be substantial, it may be necessary to be more prescriptive about the methods used by project developers to estimate and report their accomplishments.

Since the 1605(b) Guidelines were published in 1994, an extensive literature has developed to address baseline development and leakage in project evaluation (Chomitz, 1998; Chomitz, 2000; Michaelowa and Dutschke, 1999; Moura-Costa and Stuart, 1999; Aukland et al., 2003; Schwarze et al., 2002; Sohngen and Brown, 2004). Although sequestration projects have continued to expand and be successfully implemented in the United States, questions continue to arise about whether it is possible to preserve the integrity of the emission limits of a large-scale cap-and-trade program while allowing for broad use of credits from projects in uncapped sectors. Until recently, attempts to meet these twin objectives have relied on a variety of safeguards, including case-by-case expert evaluation of reference cases and leakage estimates; restrictions on the types of projects allowed in the system; limitations on the use of project-generated reductions; and discounting of the tons achieved as a proxy for leakage.

It is still unclear how the recently published revisions of DOE's 1605(b) will strike the balance as the government drives to simultaneously reduce the burden of reporting and increase the quality of the reports. Meanwhile, the State of California has developed and published guidelines for parties reporting to its greenhouse gas registry. Several nongovernmental organizations have also developed standardized procedures providing guidance on estimating the impacts of the GHG reduction and carbon sequestration projects. All of these procedures are relatively new and will warrant close attention as they are applied, critiqued, and evaluated.

In summary, desirable features of a climate change mitigation program that includes awarding credits to individual projects in the forest and agricultural sectors would include:

- A description of accepted practices for sampling and measuring carbon stocks at the project site;[22]
- Methods to develop reference cases or baselines against which observed changes in carbon levels can be compared. Several different approaches to reference case development may be needed to accommodate the wide range of potential activities and settings (see Table 1);
- Methods to estimate or address the leakage effects, including permanence, geographical leakage, and trade-offs among different GHGs;
- Program methodologies designed to provide results that are reproducible by competent, independently-operating evaluators.

A broad results-based program that provides rewards to project developers in proportion to the amount of additional carbon sequestered has the potential to improve the cost-effectiveness of a national program for mitigating greenhouse gas emissions. A results-based program is also likely to result in more innovative solutions than practice-based approaches. However, some observers still question whether the government—in cooperation with researchers, landowners, and project developers—can develop project measurement and monitoring methods that are sufficiently accurate and reproducible to protect the environmental integrity of a large-scale program that allocates rewards on the basis of evaluations of individual projects. These questions can only be answered by developing and testing the needed methods. At this stage, the goal of any program should be continual improvement, not absolute accuracy. The policy challenge, therefore, is to design programs that not only encourage improvement, but also allow improvements to be incorporated into the program on a regular basis. "Locking in" measurement and monitoring methods at the outset will potentially hinder the improvements needed for strengthening programs over time.

## V. Conclusions: Developing a Coherent National Strategy for Carbon Sequestration

*The United States can capitalize on its substantial natural, institutional, and human resources to develop a strong, integrated, carbon sequestration program.* The goals of a national sequestration strategy should include:

- Achieving actual increases in carbon stocks on its forest and agricultural lands,
- Maintaining existing carbon stocks,
- Producing more reliable estimates of changes in the absolute levels of these stocks, and
- Developing the methods needed to allow policy-makers to evaluate the effectiveness of government-sponsored sequestration programs.

Given the variety of activities, land types, and ownership patterns involved, policy-makers will need to include several different components in designing a national strategy for U.S. forest and agricultural lands. They will also need to draw on a variety of approaches to implement this strategy. To maximize results, government should employ the full range of policy tools at its disposal, including: direct government provision of information and increasing carbon on federal lands, regulations, practice-based incentives, and results-based mechanisms. Table 10 provides a summary of the many policy tools available to the government for implementing a national carbon sequestration program. Given the multiplicity of policy tools and mechanisms available, it will be important to assure that future programs complement each other and are presented to potential participants in a lucid manner.

As a first step in increasing carbon sequestration, the government should examine how it can modify management practices on its extensive land holdings to emphasize carbon sequestration in a manner that is consistent with other land management objectives such as habitat protection, erosion control, and timber production. The most promising avenue involves reducing the risk of catastrophic loss of forests to wildfires (see Box 2, page 17). The regulatory approach, which may be particularly helpful in preserving existing forests and decreasing losses of forest carbon on private land, must be implemented through state

*Table 10*

## Summary of Key Characteristics of Policy Tools

| Policy Tool | Description | How GHG Goal is Set | Monitoring and Measurement Approach | Who Bears the Financial Burden | Comment |
|---|---|---|---|---|---|
| **Government Production** | Government uses own resources to increase carbon sequestration | Quantity target or budgetary constraint | Ex post program evaluation | Government/ taxpayers | Potential political resistance to government acquisition of new land. May be limited to modified management on existing government holdings |
| **Command-and-Control** | Compliance with regulations; civil/criminal penalties for noncompliance | Quantity-based target or Technology/practice-based regulation | Inspection for compliance | Private sector | Potential political resistance to government (especially federal) control of private land-use and management decisions |
| **Practice-based Contracts or Subsidies** | Money payment for adoption of carbon-enhancing practices across negotiated number of acres (contract) or general offer of money payment or tax advantage in $/acre to any adopters of specified practice (subsidy) | Quantity-based target (acres) or price-based target ($/acre) | Inspection for adoption of practice, number of acres | Government/ taxpayers | Similar to Conservation Reserve Program. Requires government to raise additional revenue through taxes. |
| **Practice-based Tax** | A levy in $/acre on specified activities that decrease land-based carbon sequestration | Price-based target ($/acre) | Inspection for activities that release carbon, number of acres | Private sector | Potentially useful for preventing leakage; likely to face stiff political resistance among landowners |
| **Practice-based Credits** | Award of credits per acre, for adoption of specified practices | Quantity-based target on fossil fuel sources of emissions (tons) | Inspection for adoption of practice, number of acres | Depends upon specific program design | Only applicable in conjunction with a cap-and-trade program for emissions |
| **Results-based Contracts or Subsidies** | Monetary payment for a negotiated amount of carbon sequestration (contract) or general offer of monetary payment or tax advantage in $/ton to any landowner (subsidy) | Quantity-based target (tons) or price-based target ($/ton) | Estimation of amount of additional carbon | Government/ taxpayers | Requires government to raise additional revenue through taxes. |
| **Results-based Tax** | A levy in $/ton on releases of terrestrial carbon | Price-based target ($/ton) | Estimation of amount of released carbon | Private sector | Potentially useful for preventing leakage; likely to face stiff political resistance among landowners |
| **Results-based Credits** | Award of credits in tons of credit per ton of sequestered carbon | Quantity-based target on fossil fuel sources of emissions (tons) | Estimation of amount of additional carbon | Depends upon specific program design | Only applicable in conjunction with a cap-and-trade program for emissions |

governments where the power to directly control land-use and management is vested. Recent experience suggests that private-sector certification programs like the SFI that promote adoption of best management practices for sustainable forests can provide an important supplement to state and local regulations.

In the past, the federal government has predominantly employed practice-based incentives to influence private landowner decisions. This tendency is reflected in the 2002 Farm Bill, which contains a number of programs that provide cost-sharing incentives for practices that enhance carbon stocks on the lands where the practices are adopted. These programs generally serve multiple objectives that include soil, water, and habitat conservation in addition to carbon sequestration. The 2002 Farm Bill increased funding for these programs substantially. Practice-based incentive programs have two advantages as vehicles for promoting carbon sequestration. First, they operate through established networks of organizations to implement the policies. This reduces both the financial and political costs of shifting the focus of farm programs toward carbon sequestration. Second, practice-based programs avoid the transaction costs associated with measuring, monitoring, and tracking site-specific changes in carbon stocks. They also rely on a less intrusive monitoring process since it is only necessary to check for the existence and extent of the practice, rather than determining actual carbon stocks. Thus, practice-based programs are likely to be the most cost-effective, familiar, and feasible components of a larger national strategy to promote carbon sequestration, at least in the near term.

To fully exploit the potential of practice-based approaches, the U.S. government must assure continued funding for the relevant programs. Volatility in program funding will reduce the effectiveness of the government's financial resources as landowners hesitate to make long-term commitments due to programmatic uncertainty. The government should also establish a high priority research initiative to evaluate the carbon benefits and cost-effectiveness of Farm Bill initiatives. In particular, the research should examine whether the programs are inducing actual changes in practices beyond what landowners would have done in the absence of incentives. As these programs mature, the government should revisit the question of whether practice-based programs should be expanded. For example, if the Conservation Reserve Program (CRP) proves particularly successful, the government should consider increasing its funding level and removing the current cap of 39.2 million acres.

An important element of a national strategy will be to explore whether it is possible to develop a credible program incorporating results-based incentives for individual carbon sequestration projects. Results-based approaches have the advantage of providing high-powered incentives for innovative approaches to carbon sequestration. However, they are also less familiar than the well-established practice-based approach, and will require both overcoming information challenges and choosing among several options.

The first step to developing a program that bases incentives on the results of individual projects is to establish a viable, cost-effective method of measuring impacts of practice and land-use changes in specific locations. The government appears to have started this process with its program to reassess and redesign the 1605(b) reporting guidelines. Whether those revisions will provide guidelines that are adequate for a cap-and-trade program remains to be seen. Ultimately guidelines will need to provide methods that address development of reference cases, potential leakage, permanence, and effects on other greenhouse gases in a manner that is sufficiently clear and comprehensive so that independent evaluators of a given project will arrive at essentially the same estimate of carbon benefits.

The second step to adding a results-based approach to the national strategy is to determine how incentives will be provided to project developers. For example, the government could provide subsidies or contracts where payments to landowners are proportional to the amount of carbon actually sequestered. Alternatively, if there are caps on emissions of greenhouse gases from industrial sources, project developers might receive credits issued by the government, but the payments to project developers would come from sales of these credits to industrial sources which would use the credits to assist in meeting emissions limits.

Once key stakeholders are satisfied that methods are available that accurately assess the carbon effects of individual projects, then a results-based program for promoting carbon sequestration on agricultural and forestlands should be included in the national carbon strategy. Doing so will unleash the creativity and innovation of U.S. landowners and lead to lower overall costs of achieving national climate goals.

Opportunities for augmenting carbon sequestration may be even greater, and costs may be substantially lower, in developing countries than in the United States. Therefore, U.S. policy-makers should consider expanding the scope of a sequestration strategy to provide incentives for projects outside U.S. borders. The U.S. government could also work directly with other governments to identify, promote, and fund new policies and practices that will protect and increase carbon stocks in those countries. The incentives could be largely the same as for domestic initiatives, and could include practice-based or results-based payments. However, the process for including results from efforts in other countries in the national report would be different. Whereas the impacts of domestic initiatives would be included automatically in the inventory of national carbon stocks compiled by the United States under the U.N. Framework Convention on Climate Change, inclusion of international accomplishments would not be automatic (see Figure 1). Sequestration benefits achieved in other countries would have to be measured separately. The sum of these impacts would then be added to the national change in domestic stocks to estimate the total change in global carbon stocks for which the United States might claim credit. If the national strategy includes incentives for sequestration accomplishments in other countries, it will become even more critical to develop consistent methods for program and project evaluation.

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## Endnotes:

1. A short ton = .907 metric tons.

2. For a discussion of conservation tillage, see Chapter III, Section C. Forest certification refers to a variety of programs under which third-party auditors certify that the management practices used for a particular forest stand conform to specified environmental standards.

3. Farm and forest statistics are not directly comparable, because the definition of a "farm" is an enterprise that sells more than $1,000 of agricultural products per year, while the definition of "forest" is an area larger than 1 acre that is covered with trees. The farm definition leaves out a large number of "hobby" or non-commercial farms and large-lot homesites that have pasture or other non-forested land. There is overlap between the two sets of statistics because many farms contain some forestland. Birch (1996) estimated that 738,000 forestland owners were farmers. At this point, there are no readily available statistics that would categorize all rural landowners in a comparable fashion.

4. Afforestation is the establishment of tree cover on land that has previously been in a non-forest use, such as cropland or pasture. Reforestation is the establishment of trees on land that has not been taken out of forest use, but for some reason has not regenerated an adequate forest stand after the previous forest was removed or destroyed.

5. One study of forest inventory data for the western United States suggested that an average of 15 tons of biomass fuel could be harvested per acre, and that a fuel treatment program in the western United States, spread over ten years would produce over 40 million bone dry tons (BDT) of biomass fuel per year (Sampson et al., 2001). It takes on the order of 180,000 BDT per year to run a 20 MW plant, thus requiring recovering fuel from about 12,000 acres. This means that, on a 30-year harvest rotation, a 20 MW plant needs about 360,000 acres of accessible forest needing thinning within 50 road miles. 360,000 is approximately 7 percent of the land area of a 50-mile radius circle.

6. Proper application of fertilizers, including amount, timing, and formulation can also be an important contributor to reducing the risk of air and water pollution.

7. There are important pools of soil inorganic carbon (SIC) compounds such as calcium carbonate (lime) in agricultural soils as well, but their fluxes in response to management are not well known, so changes in SIC are not estimated in most sequestration calculations at this time.

8. Rangelands are defined as "land on which the historic climax plant community is principally native grasses, grass-like plants, forbs, or shrubs suitable for grazing and browsing." Pasturelands are defined as "land used primarily for the production of introduced or native forage plants for livestock grazing" (USDA-NRCS, 1997). The distinction, therefore, is largely on the basis of the intensity of land management, where pastureland is more intensively managed with practices such as periodic plowing and re-establishment, fertilization, irrigation, or other inputs designed to increase forage production.

9. The actual period of time over which the sequestration would occur might be shorter or longer than one hundred years, depending upon the specific species of tree and the location of the land involved. The figures in the cited study were converted to a time-weighted (amortized) equivalent yield over 100 years using a five percent discount rate. The conversion provides comparability across studies, as well as species and locations.

10. Opportunity cost is an indication of what must be sacrificed to obtain something. In the environmental context, it is a measure of the value of whatever must be sacrificed to prevent or reduce the chances of a negative environmental impact or achieve a positive environmental impact. (Stavins and Richards, 2005). Early cost-effectiveness studies suggested that conversion of marginal agricultural land to forests could sequester as much as 600 million tons of carbon per year at costs ranging from $10 to $60 per ton (Richards et al., 1993; Adams et al., 1993). Subsequent more sophisticated econometric studies indicate that the cost may be substantially higher due to countervailing market responses and landowner reluctance to commit to long-term forest production (Stavins, 1999; Plantinga et al., 1999). According to one study, the marginal costs for a national program designed to capture 500 million tons per year through conversion of agricultural land to forests would exceed 100 dollars per ton (Stavins, 1999).

11. The FIA has not historically included the collection of statistically valid data on the National Forest System, the National Park System, or other federal lands, and has avoided the low-producing forests (those that produce less than 20 cubic feet of merchantable wood per acre per year and therefore are not defined as "timberland" in the Forest Service system). The NRI is limited to non-federal lands, so it produces no data at all on the federal land base. There are plans to increase the monitoring of federal lands in the future, but it will be many years before useful trend data are developed.

12. In general, when the government raises a dollar of revenue through taxes, the cost to its citizens is greater than a dollar, perhaps quite a bit more. In general, instruments that require the government to raise revenue to make payments to private parties will have a greater social cost than those that do not require additional financial resources for the government.

13. Technical assistance refers to on-site land management assistance by a qualified resource professional. A major problem with technical assistance is that each new client requires a significant amount of time; so increased program levels mean increased personnel needs. As these programs reach more people and more acres, they also reach landowners with less sophistication in practical management. This means that the hours per landowner/acre rises, and program cost-effectiveness declines.

14. The forest products industry, through its Sustainable Forestry Initiative (SFI), works to educate landowners on sustainable forestry objectives and techniques (AF&PA, 2002). This is a new private sector initiative (created in 1995), and its effectiveness remains to be seen. Prior education efforts by the industry were carried out through its support and management of the Tree Farm Program, which is still in operation. In agricultural conservation, the private sector promotes conservation practices such as no-till farming and the prevention of water pollution. A leading example is the Conservation Technology Information Center, a cooperative effort that involves the National Association of Conservation Districts, a significant number of private firms from the machinery, chemical, seed, and agricultural sectors, and several federal agencies (CTIC, 2002). One of the major outcomes of these private education programs is that people are motivated to take advantage of other, governmental, forms of assistance such as technical assistance or cost sharing (Baughman, 1993).

15. Under a cap-and-trade program, emissions from some sources—typically large point sources—are limited. These sources must submit an allowance for each ton they emit. However, some emissions often are not covered under such a program—typically including emissions from agricultural and forestlands. The program can allow reductions from these "non-limited" sources to be used by sources whose emissions are limited to meet program mandates. If so, emission reductions by sources not covered under the program are awarded credits which can be used as allowances by sources which need to submit an allowance for each ton of emissions.

16. Generally, rational project developers will undertake carbon sequestration projects when the value of allowances or other payments exceeds the cost of the project. In a cap-and-trade program of the type described, project developers will undertake sequestration projects up to the point where the additional cost of carbon sequestration is equal to the marginal cost of emissions reductions in the capped emissions sectors. In the abstract this is a roughly efficient outcome.

17. It is commonly assumed that a program would employ a one-to-one reward structure in terms of emissions allowances per ton of sequestration; e.g., 100 ton of emissions allowance for 100 tons of sequestration. However, there may be variety of reasons related to uncertainty, leakage, impermanence, other programmatic issues or even politics that would lead the government to adopt a ratio of less than one-to-one: in effect, to discount these credits.

18. Accuracy is how close to the actual value the sample measurements are. Accuracy details the agreement between the *true value* and *repeated measured observations* or estimations of a quantity. Precision is how well a value is defined. In sampling, precision illustrates the level of agreement among *repeated measurements* of the same quantity. This is represented by how closely grouped the results from the various sampling points or plots are.

19. Forest carbon is measured with standard field techniques that normally consist of physically measuring tree diameter and often height within sample plots located by a statistically designed plan. Tree measurements are then converted to estimates of total carbon through the use of empirical equations developed by forestry researchers that relate tree diameter (or tree diameter and height) to carbon content (Brown, 2002; Brown and Masera, 2003). The carbon content in other forest components such as shrubs, dead wood, and other dead organic matter is generally measured directly through the use of standard field techniques. Examples of standard field techniques can be found in A Guide to Monitoring Carbon Storage in Forestry and Agroforestry Projects; available at http://www.winrock.org/REEP/PDF_Pubs/carbon.pdf.

20. The number of plots needed is a function of how variable (measured by coefficient of variation) the changes in carbon stocks are expected to be and what precision level is desired for the carbon measurements. For a given precision level, the more variable the project area the more plots are needed; and for a given variability more plots are needed to achieve higher precision. The coefficient of variation is a statistical term and is equal to the standard deviation of the sample divided by the mean of the sample.

21. The 95% confidence interval means that there is a 1 in 20 chance the true value lies outside the interval boundaries.

22. Comparing the results of reports in the existing 1605(b) database can be difficult due to a lack of consistency in methods and units. Some project results are reported in English units while others employ metric units. Some sequestration projects report changes in carbon stocks while others report changes in flows. In some cases it is difficult to determine the exact location of the project. The reporting and measuring system should provide a set of standard definitions and measurement units that lead to clear, consistent, reliable reports; and records should include the physical locations of projects.

# notes

This report describes the ways in which U.S. forest and agricultural lands can assist in reducing net greenhouse gas emissions and reviews policy approaches that promote these opportunities. The Pew Center on Global Climate Change was established by the Pew Charitable Trusts to bring a new cooperative approach and critical scientific, economic, and technological expertise to the global climate change debate. We inform this debate through wide-ranging analyses that will add new facts and perspectives in four areas: policy (domestic and international), economics, environment, and solutions.

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